

**THE HYDROGEOLOGY
OF THE
BENNETT SPRING AREA,
LACLEDE, DALLAS,
WEBSTER, AND WRIGHT COUNTIES,
MISSOURI**

by

James E. Vandike

Cover Photo: *Bennett Spring Branch just downstream of the spring rise.*

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1992



MISSOURI DEPARTMENT OF NATURAL RESOURCES

Division of Geology and Land Survey

P.O. Box 250, Rolla, MO 65401

(314) 368-2125

Library of Congress Catalog Card Number: 92-064210
Missouri Classification Number: Ge 9:38

Vandike, James E., 1992, ***THE HYDROGEOLOGY OF THE BENNETT SPRING AREA, LACLEDE, DALLAS, WEBSTER, AND WRIGHT COUNTIES, MISSOURI***, Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report Number 38, 112 p., 44 figs., 26 tbls, 14 photos.

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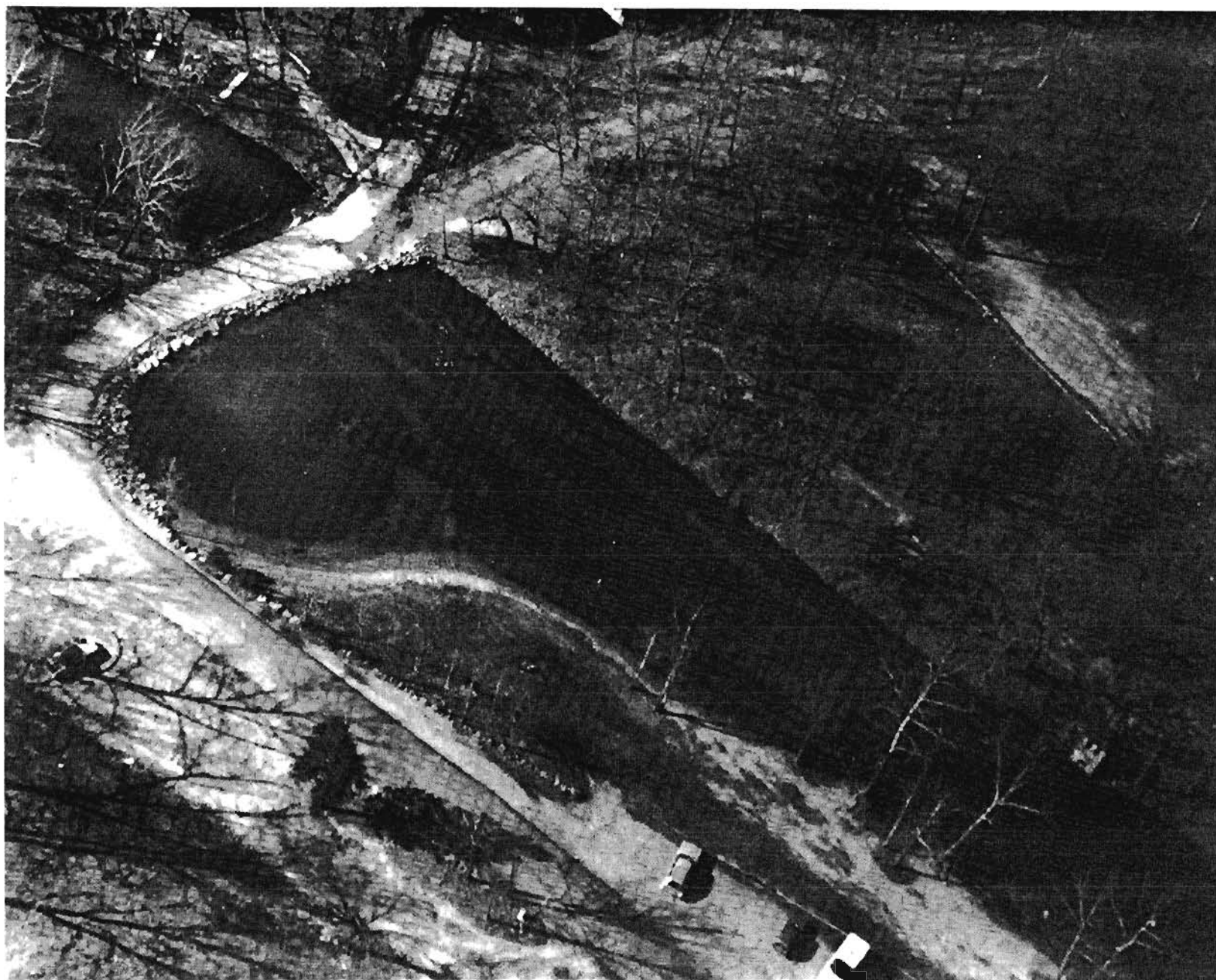


Photo 1: The circular rise pool of Bennett Spring, clearly seen from the air, is on the east side of Spring Hollow about a mile from the Niangua River. Much of the time, flow of the Niangua River more than doubles when the discharge of Bennett Spring enters it..

THE HYDROGEOLOGY OF THE BENNETT SPRING AREA, LACLEDE, DALLAS, WEBSTER, AND WRIGHT COUNTIES, MISSOURI

ABSTRACT

Bennett Spring, Missouri's third largest single outlet spring, has an average discharge of about 165 ft³/sec, and is the principal groundwater outlet for an extensive karst area in south-central Missouri. A hydrologic reconnaissance in the Bennett Spring area of Laclede, Dallas, Wright, and Webster counties, which includes the upper Niangua River, Osage Fork of the Gasconade River, and Dry Auglaize Creek, identified nearly 40 streams that lose significant volumes of surface flow into the karst groundwater system. Dataloggers and pressure transducers installed at four locations on three losing streams to help quantify losing-stream water-loss rates show most runoff from precipitation is channelled underground and becomes groundwater recharge. During water year 1989-1990 when area precipitation was nearly 46 inches, there was only about 2.5 watershed inches of runoff from Spring Hollow, a 42.5 mi² losing-stream watershed upstream from Bennett Spring.

Eighteen dye traces were made to nine springs from 14 dye-injection sites in the Bennett Spring area to help delineate areas providing recharge to major springs, and to determine groundwater velocities in the karst drainage system. Velocities varied from less than 0.2 miles per day to more

than 1.3 miles per day. The Bennett Spring recharge area, based on water tracing and existing potentiometric map data, consists of a 265 mi² area east, south, and southwest of the spring. The recharge area includes Spring Hollow, upper Fourmile Creek, upper Dousinbury Creek, and East Fork Niangua River in the upper Niangua River basin; Brush Creek and North Cobb Creek in the Osage Fork Basin; and Goodwin Hollow, a tributary of Dry Auglaize Creek. Dye tracing showed Bennett Spring to share a part of its recharge area with Jake George Springs and Sweet Blue Spring. Sand Spring and Famous Blue Spring, smaller springs near Bennett Spring State Park, share a common recharge area south of the Niangua River in Cave Creek and lower Fourmile Creek watersheds.

Precipitation, discharge, and specific conductivity data show that the discharge of Bennett Spring begins increasing generally within a few hours after precipitation due to pressure-head increase in the recharge area, but the water introduced into the aquifer from a precipitation event does not reach the spring for several days. The magnitude of flow increase depends greatly on soil moisture conditions; greater flow increases occur after precipitation when soils are wet than during relatively dry conditions.

INTRODUCTION

Bennett Spring, the focal point of Bennett Spring State Park, is the third largest single outlet spring in Missouri and the largest spring in the state park system. During an average day, the extensive phreatic cave system feeding the spring outlet channels approximately 103 million gallons (165 ft³/sec) of water to

the surface; water that originated as precipitation falling over a broad area east, south, and southwest of the spring. The spring rises from a steeply-inclined, water-filled cave passage on the east side of Spring Hollow about 1.3 miles upstream from its confluence with the Niangua River.

Each year, some 800,000 people visit Bennett Spring State Park to take advantage of the outdoor recreational opportunities that include hiking trails, picnic areas, campgrounds, and trout fishing along Spring Hollow downstream of Bennett Spring. Bennett Spring water also supplies a Department of Conservation trout hatchery.

Currently, water quality at Bennett Spring appears excellent. However, water quality can be affected by the activities of people in the area supplying recharge to the spring. Land-use changes, improper waste disposal, and accidental spills of potentially toxic materials in the recharge area could degrade water quality.

In 1989, the Department of Natural Resources began a study designed to improve our understanding of the hydrology of Bennett Spring, to delineate the area providing its recharge, and to study the surface-subsurface relationships in the area. The study area includes the Niangua River basin, the Osage Fork of the Gasconade River basin, Goodwin Hollow and Dry Auglaize Creek basins, and that part of the Gasconade River basin west of the Gasconade river in Laclede County. The study area includes all of Laclede County, and portions of Dallas, Webster, and Wright counties, Missouri (fig. 1).

ACKNOWLEDGMENTS

Though this report bears the name of one author, the combined efforts of many individuals helped greatly to improve its quality. Much of the precipitation data were collected by volunteers interested in the study. Ray and Barney Bryant, Bill DeVasure, Dexter Holmes, Michelle Jones, Dennis and Sue Johnson, Mark King, Roy Knight, Ralph Massey, and Diane Tucker collected daily precipitation data specifically for this study, and their efforts are sincerely appreciated. Thanks also go to Jackie Clark for providing precipitation data collected by the Missouri Department of Conservation office at Lebanon. John Fowler, Ed Terry, and Mrs. Lolan Howerton are National Weather Service observers at Lebanon, Marshfield, and Buffalo, respectively. All were kind enough to submit temperature and precipitation data at the end of each month. Bob Russell allowed installation of the tipping bucket rain gage and event recorder at his farm west of Lebanon, and supplied electricity to heat the equipment during two winters.

Cynthia Brookshire helped install the pressure transducers and dataloggers. The installations were made without benefit of a back hoe, which required considerable trenching using a pick and shovel. Her hard work is greatly appreciated. Special thanks also go to the staff at Bennett Spring State Park, particularly Sam Allen, Park

Superintendent, and naturalists Diane Tucker and Dana Holsington for their interest in the project and aid in data collection.

Special thanks are due to Susan Dunn for her excellent work in developing and completing the final layout for this report.

Companies owning pipelines which cross the study area supplied pipeline location maps and other data. I thank the Conoco Pipe Line Company, the Explorer Pipeline Company, Shell Pipe Line Corporation, and Williams Telecommunications Company, for their contribution to this study.

Most of the study area is private property. Three pressure transducer-datalogger gaging stations were installed on property owned by Lester Evans, Mark King, and Dee Cole. I appreciate them allowing installation of the equipment and access to the sites. Many other interested property owners helped by allowing access to springs and streams, providing historical information, and allowing dye traces to be conducted from their properties. This study could not have been successful without the cooperation of these and many other people. I appreciate their interest and cooperation, and hope the results are worth their efforts.

STUDY RATIONALE AND METHODOLOGY

Recharge area protection is of paramount importance in maintaining high water-quality standards at Bennett Spring. This study was designed to provide the type of information necessary to help prevent water-quality degradation in the area by delineating the recharge area for Bennett Spring, by developing a conceptual model to describe how, where, and at what rates recharge occurs, by defining surface-subsurface hydrogeologic relationships, and then using this information to develop an initial water-quality risk assessment for the Bennett Spring recharge area. However, it was more than a study of just Bennett Spring. Many other significant springs occur in the study area. Like Bennett Spring each one has a recharge area and distinct hydrogeologic characteristics. Hydrogeologic data is used to help delineate their recharge areas, and better define the functioning of their supply systems.

An area-wide hydrologic reconnaissance was performed to determine which areas contribute significant groundwater recharge and which areas contribute little recharge. Much of the Bennett Spring recharge is from runoff into sinkholes and losing streams; both channel tremendous volumes of water into the subsurface following heavy rainfall. Losing and gaining stream reaches were mapped during the hydrologic reconnaissance to determine the areas providing high rates of groundwater recharge.

Obviously, not all of the sinkholes and losing streams in the study area contribute recharge to Bennett Spring. Dye tracing, a technique where by fluorescent dyes are introduced into the subsurface through sinkholes and losing streams, and detected at the spring or springs where they emerge, was used to help delineate the recharge areas for the major springs in the study area.

Considerable geologic and hydrologic data are available for the Bennett Spring area through previous studies and ongoing basic data collection activities. Historic flow data are available for the Niangua River, Osage Fork, and Gasconade River from the U.S. Geological Survey. Bennett Spring's flow has been monitored for about 40 years by the U.S. Geological Survey. Nearly all of the surface-water flow data has been collected from major perennial streams. To better under-

stand the runoff characteristics of smaller watersheds that lose flow into the subsurface, hydrologic instruments were installed on selected losing streams to help determine rainfall-runoff relationships in these important recharge areas. Also, a network of precipitation stations was established in the study area to supplement National Weather Service precipitation data in order to more accurately measure the water available for runoff and recharge during the study.

Area temperature and rainfall data were used to develop a hydrologic budget for the study area. A hydrologic budget is a mathematical procedure used to describe water distribution in an area. It allows losses from evaporation and vegetational use of water to be estimated, as well as an estimation of the amount of water available for surface-water runoff and groundwater recharge. Hydrologic budgets were calculated for two periods of time. A daily budget was prepared for water year 1989-1990, which extends from October 1, 1989, through September 30, 1990. A monthly budget was prepared for water years 1956 through water year 1990, to show long term water distribution in the Bennett Spring area.

Specific conductivity and water temperature data were collected from Bennett Spring and other groundwater outlets in the Bennett Spring area. Specific conductivity is a measurement of water's ability to conduct electrical current. Specific conductivity is directly proportional to the amount of dissolved materials in water; as dissolved solids increase, conductivity increases. In this study, the conductivity data are used primarily to determine when recharge from rainfall events reaches a spring. Temperature data can be used to help determine the type and relative amount of recharge taking place, and to help understand the mechanics of the flow-system channelling water to the springs.

A preliminary water-quality risk assessment was performed on Bennett Spring using recharge area data generated during the study, potential contaminant source data available from the Department of Natural Resources' Division of Environmental Quality, and from highway, railroad, and pipeline information.

The Hydrogeology of the Bennett Spring Area

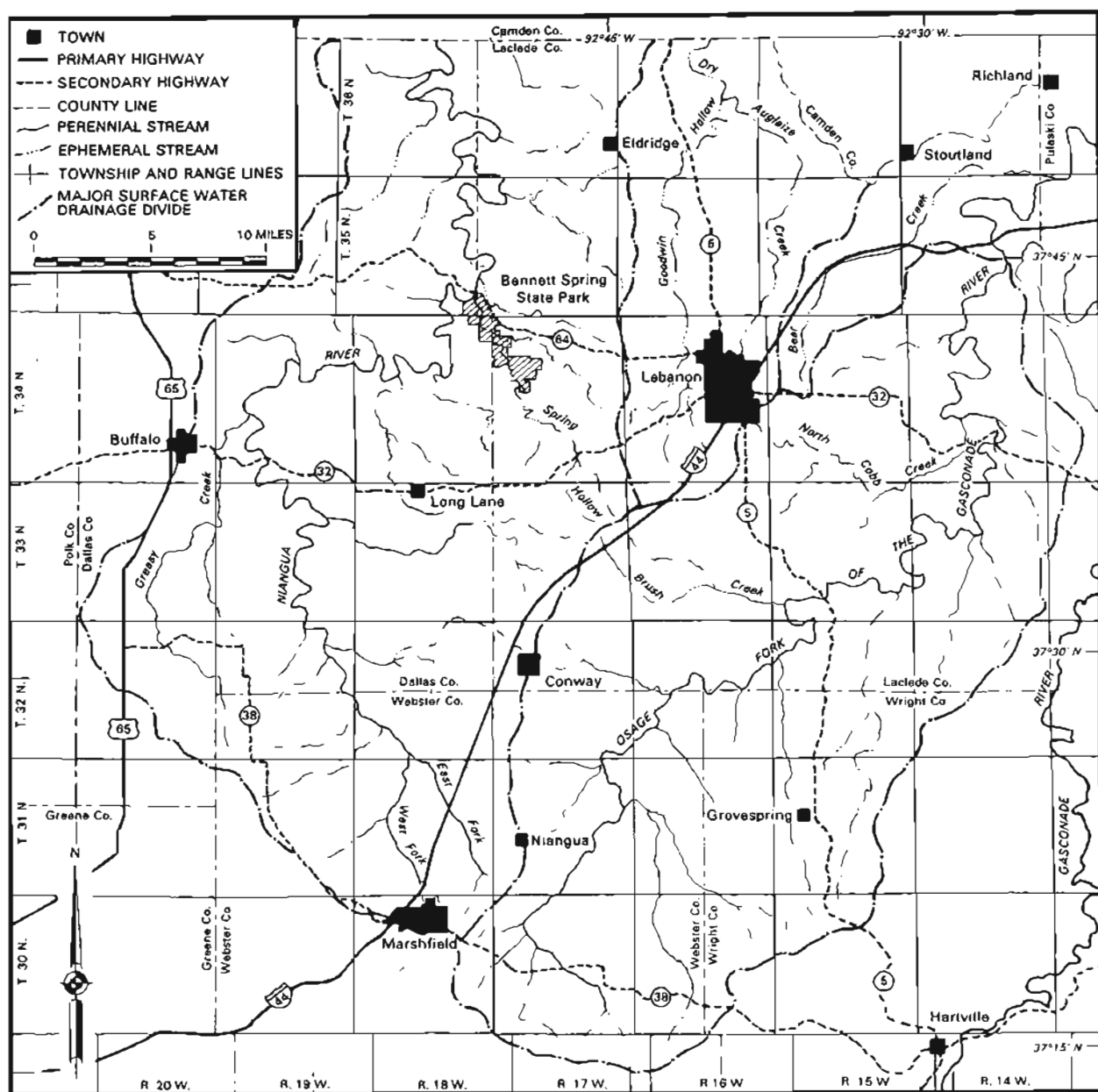


Figure 1: Location map showing the Bennett Spring area.

GEOLOGY OF THE BENNETT SPRING AREA

INTRODUCTION

A detailed description of the geology of the Bennett Spring area is beyond the scope of this study, but a general understanding of the geology and its relation to hydrology of the area is necessary. Harvey et al. (1983) present an excellent description of the stratigraphy and structural geology of the area.

STRATIGRAPHY

The Bennett Spring area is underlain mostly by sedimentary rocks of Ordovician and Cambrian age that reach a thickness of about 1800 feet. Younger strata of Mississippian age occupy the higher elevations along the Niangua River-Osage Fork watershed divide in Webster and Dallas counties. Nearly all of the bedrock formations exposed in the study area are Ordovician (Canadian Series) sedimentary rocks. The oldest sedimentary bedrock formations underlying the area are Upper Cambrian age. They include, in ascending order, the Lamotte Sandstone, Bonneterre Formation, Davis Formation, Derby-Doerun Dolomite, Potosi Dolomite, and Eminence Dolomite. The only place upper Cambrian strata are exposed in the study area is at the Decaturville structure, an intensely faulted, geologically complex, circular structure in northwestern Laclede County. The geology of the Decaturville structure is described in detail by Offield and Pohn (1979), who interpret it as an impact structure. The Eminence Dolomite is also exposed a few miles north of the study area in southern Camden County in the Ha Ha Tonka State Park area.

With the exception of the Decaturville structure, the oldest bedrock formation exposed in the study area is the Gasconade Dolomite. The Gasconade is a light gray, medium- to coarse-crystalline, thin- to thick-bedded cherty dolomite consisting of two units. The Upper Gasconade is massively bedded with a relatively low chert content that can be as much as 100 feet thick. In contrast, the Lower Gasconade, ranging in thickness from about 270 to 380 feet, has a relatively high chert content. The chert occurs as thin beds, nodules, and cryptozoan reef structures up to several feet thick (Duley et al., 1992). The Gunter Sandstone

Member, generally 30 to 45 feet thick, forms the base of the Lower Gasconade. Sand content in the Gunter varies from less than 40 percent in the southeastern part of the study area to 100 percent in northwestern Laclede County (Harvey et al., 1983). The Gasconade Dolomite has a total thickness ranging from about 300 to 450 feet, but only the upper 50 to 100 feet of the formation is exposed, primarily along the Niangua River and its major tributaries downstream from the Fourmile Creek area, throughout much of Spring Hollow, along the middle reach of the Osage Fork in northwestern Wright and southern Laclede counties, and along the Gasconade River in northeastern Laclede County (fig. 2).

The Roubidoux Formation overlies the Gasconade, and forms the bedrock surface over much of the east-central part of the study area. The Roubidoux is an interbedded light-gray to brownish-gray, medium- to fine-crystalline cherty dolomite and sandstone (Duley et al., 1992). Sandstone beds are conspicuous in the unit, but sand content decreases to the north. Full thickness of the formation ranges from about 125 to 180 feet.

The Jefferson City and Cotter Dolomites are considered distinct geologic units, but because of their similarities they are generally mapped as a single unit and referred to as the Jefferson City-Cotter Dolomite. The Jefferson City Dolomite overlies the Roubidoux Formation, and forms the bedrock surface throughout much of the eastern, southern, and western parts of the study area. The Jefferson City is a buff to light-gray, fine- to medium-crystalline, thin- to thick-bedded argillaceous dolomite (Duley and others, 1992). Where not eroded, it ranges from about 150 to 220 feet thick. The Cotter Dolomite overlies the Jefferson City, and consists of up to 200 feet of dolomite with chert and minor sandstone beds. Due to its high stratigraphic position, it occupies mainly the upland areas in the southern and southwestern parts of the study area.

Up to about 130 feet of Mississippian sedimentary rocks unconformably overlie the Cotter Dolomite along the watershed divides in the southern and southwestern parts of the study area; they

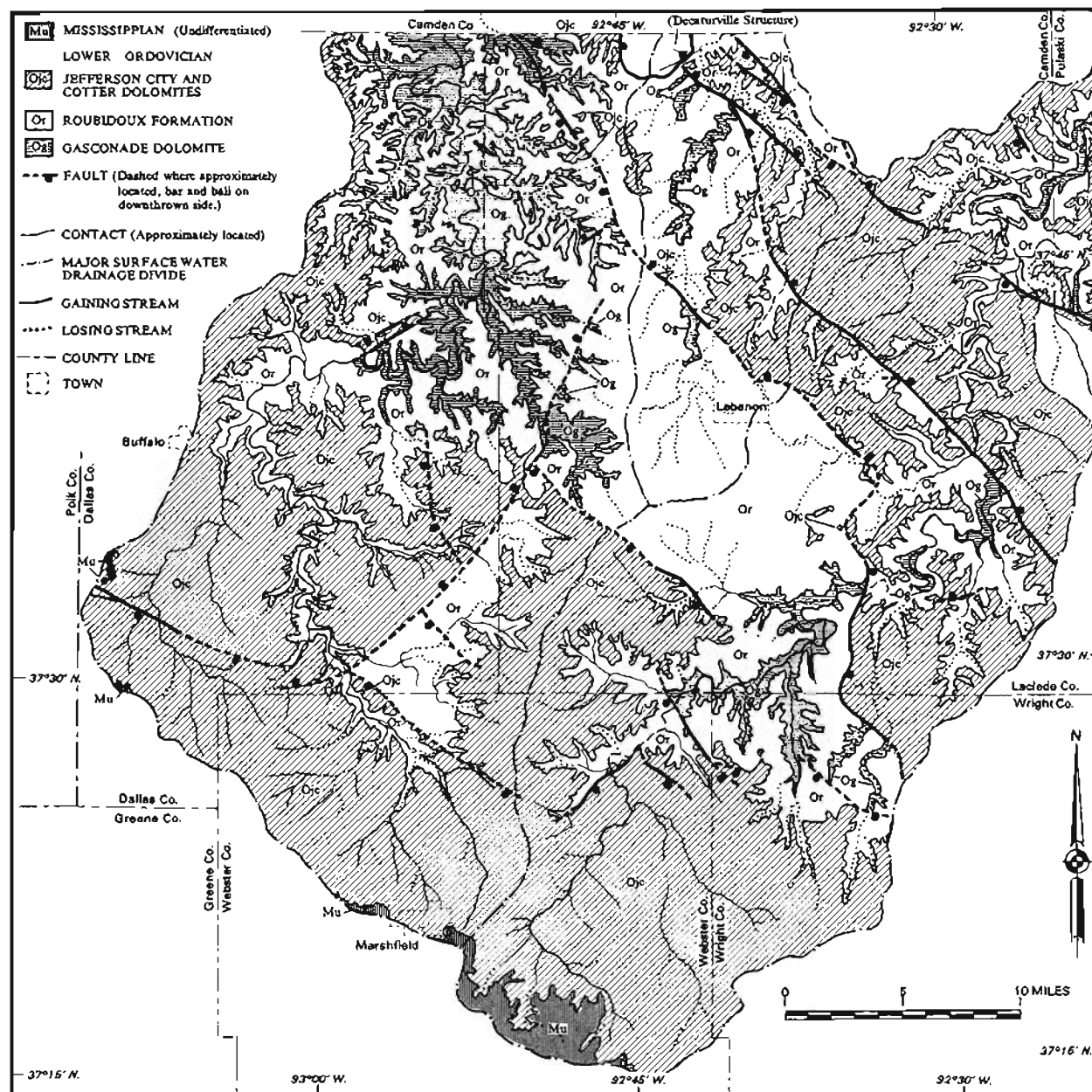


Figure 2: Geologic map of the Bennett Spring area. Geology by Middendorf et al., 1987.

occupy only the higher elevations. They consist primarily of the Compton and Northview Formations, and the Burlington-Keokuk Limestone. A few miles west of the study area on the Springfield Plateau, the Mississippian units thicken and comprise a shallow aquifer. In the study area they are not hydrologically significant, and will not be discussed in detail in this report.

SURFICIAL MATERIALS

Except where outcrops occur, bedrock in the study area is mantled by unconsolidated surficial materials consisting of clay, silt, sand, gravel, and boulders that were principally derived from the weathering of bedrock formations. Most of the surficial materials are residuum, which is the insoluble material left from *in situ* weathering of the bedrock. The residuum consists of clay, silt, and chert; the relative proportions of each depending on the parent rock formation, topography, and other factors. Residuum formed from weathering of the Roubidoux Formation generally contains more gravel and larger chert fragments and has less clay content than residuum derived from the Jefferson City and Cotter Dolomites. Residuum in the study area ranges from zero to more than 40 feet thick in areas where deep bedrock weathering has occurred.

Colluvium, sediment that has been eroded and transported downslope by water and gravity, is limited to lower valley slopes in some areas. A relatively small amount of loess, (wind-blown silt)

is found on residuum in upland areas that have gentle slopes.

Alluvium, which consists of sand, gravel, boulders, and finer sediments, underlies the floodplains of major streams in the area. It is generally only a few feet thick along smaller streams, but may be 30 feet thick in places along the lower Niangua, Osage Fork, and Gasconade Rivers.

STRUCTURAL GEOLOGY

All of the exposed formations in the study area are marine sedimentary rocks that were deposited horizontally, but tectonic forces acting on the formations long after deposition caused faulting and gentle folding. Numerous northwest-trending normal faults, which likely reflect structure in the Precambrian igneous and metamorphic rocks beneath the Paleozoic sediments, trend through the study area. The faults have low to moderate displacements, generally 10 feet to as much as 400 feet (Harvey et al., 1983, p. 30). Because of the faulting and gentle folding, strata dip nearly in all directions somewhere in the study area. However, strata in the eastern part of the study area generally dip to the north and northeast while in the western part, strata dip to the west and northwest. Dips are generally less than 30 feet per mile. Structurally, the highest and lowest parts of the study area occur in the extreme southeast and northeast parts of the study area, respectively. Total structural relief is about 500 feet.

HYDROLOGY

INTRODUCTION

The hydrology of an area is usually subdivided into two categories: Surface-water hydrology and groundwater hydrology. The former refers to the occurrence and movement of water on the land surface while the latter refers to water in the subsurface. In the Bennett Spring area, as in most of the Ozarks, subsurface weathering of the carbonate bedrock has created a variety of geologic features that allow such rapid interchange between surface

water and groundwater that it is irrational to discuss one without considering the other.

The ultimate source of water in the study area is precipitation. The total amount of precipitation is the total volume of water available, but the distribution of the water in the environment depends on many factors. Depending on season and temperature, much of the water is returned to the atmosphere as evaporation or is used by vegeta-

tion. The combined loss is termed evapotranspiration. Part of the water stays on or very near the land surface and flows into streams, the amount depending greatly on soil moisture conditions, soil permeability, and rainfall intensity and duration. Another part enters the ground, moves laterally and downward until it reaches the water table, and becomes groundwater.

GROUNDWATER RECHARGE

Groundwater recharge, the process by which water enters the subsurface, can occur in several different ways by both diffuse and discrete means.

Diffuse recharge is groundwater recharge from precipitation that occurs by relatively slow infiltration of water through the soil by means of fairly small openings in bedrock until the recharge reaches the water table. The water table is the planar surface between the saturated and unsaturated zones. Above it, openings in the earth materials are not water-saturated; below it nearly all of the void spaces are completely water-filled. Diffuse recharge occurs nearly everywhere. The rate is controlled by precipitation amount and intensity, topography, and soil and bedrock permeability. Areas with low soil and bedrock permeability allow lesser quantities of water to drain downward and have higher surface-water runoff rates. In the study area, residuum developed from weathering of the Roubidoux Formation is very stony and typically, very permeable. Residuum from the Jefferson City and Cotter Dolomites, containing a higher fraction of fine-grained sediments, is usually less permeable. In upland areas, residual soils developed on the Roubidoux Formation, Jefferson City, and Cotter Dolomites typically contain a fragipan 18 to 24 inches below the surface that impedes the downward movement of water. Most of the water moves horizontally on the fragipan except where it is missing or cut by valleys and gullies (Harvey et al., 1983, p. 30).

Diffuse recharge provides a relatively small volume of recharge per unit surface area, but because this type of recharge takes place over broad areas the total volume of recharge is quite large.

Discrete recharge is the concentrated, localized movement of surface water into the subsurface. In the study area, discrete recharge occurs primarily

where surface-water runoff enters karst recharge features such as sinkholes and losing streams. Karst is a term used to describe areas where the dissolution of soluble bedrock has played a dominant role in developing topographic and drainage features. Sinkholes, one of many types of karst features present in the study area, are topographic depressions in the Earth's surface resulting from natural subsurface removal of soil and rock. They form when soluble bedrock is dissolved by slightly acidic groundwater and the dissolved materials, along with some of the remaining insoluble part of the rock, are transported underground through solution-enlarged openings in the bedrock. Over time, a void or opening develops in the shallow subsurface, enlarging to the point where its roof can no longer sustain its own weight and a collapse occurs. If the void develops mostly in residual materials and not bedrock, the resulting sinkhole will initially have nearly vertical or overhung sides; little or no bedrock will be exposed in the walls. Runoff from rainfall will erode materials around the rim of the sinkhole to form the typical bowl-shaped depression. In some cases, the collapse occurs within a cave passage or void which has developed in the bedrock. Here, the shape of the resulting sinkhole is more dependent on the configuration of the bedrock. The sinkhole may contain vertical bedrock walls along parts or all of its perimeter, and may contain enterable cave passage. The vast majority of sinkholes in Laclede County are developed in surficial materials, and few have bedrock walls visible at the surface.

There are hundreds of sinkholes in the study area, with diameters ranging from less than a hundred feet to more than a thousand feet and depths of a few feet to more than 100 feet. The area draining into a sinkhole in the study area can range from less than an acre to more than 300 acres. Sinkholes are not evenly distributed. They occur in all of the counties in the study area, but the majority are in Laclede County. Approximately 70 percent of the sinkholes in Laclede County are found within a 10-mile radius of Lebanon, primarily in the upland areas near the drainage basin divides and throughout the upper reaches of Goodwin Hollow and Dry Auglaize Creek. Sinkholes can be found in any of the geologic formations, but are most commonly developed in deeply-weathered Roubidoux Formation and Jefferson City Dolomite.

Sinkholes have a high rate of groundwater recharge per unit area. Unless ponding occurs, the amount of recharge is essentially the amount of precipitation within the topographic drainage of the sinkhole, minus the losses from evapotranspiration. This equates to an average yearly value of about 12 watershed inches. There can be no surface-water runoff from the sinkhole unless it completely fills with water. Some of the sinkholes do impound water permanently; an example is White Oak Pond along Highway 5 south of Lebanon. However, most drain quickly after precipitation, and combined they provide a large volume of discrete groundwater recharge.

Streams which carry water essentially year around and have flows that are well-maintained or increase in a downstream direction are termed gaining streams. The water table along gaining streams is at or above stream level, and groundwater moves toward and into the stream. Losing streams are just the opposite. Losing streams are discrete recharge features that allow surface water to rapidly enter the subsurface. The water table along losing streams is below stream elevation. Water in the stream enters the bedrock through solution-enlarged openings in the streambed. Some losing streams flow much of the year, but lose significant percentages of their flows into the bedrock along given reaches or at discrete points. Other losing streams carry water only briefly after intense precipitation, and are dry the remainder of the time.

Unlike sinkholes, losing streams do not necessarily channel all of their flow into the subsurface. Typically, because the water table is well below stream elevation and because of the high permeability through the loss zones, major losing streams are usually dry, often for months at a time. Most will carry water throughout their reaches following very heavy rainfall, but these flows are usually brief and the streams go dry after a few hours to a few days, depending on the volume of runoff, pre-rainfall conditions, and storage capacity of the earth materials. Lesser rainfall events may cause brief flow along stretches of the streams, but the water is typically channelled underground before travelling far on the surface. Losing streams with lesser loss and storage capacities may carry flow for several weeks during wet weather, but be completely dry during the late summer, fall, and winter months.

HYDROLOGIC RECONNAISSANCE OF THE STUDY AREA

Losing streams are the major source of discrete groundwater recharge in the Bennett Spring area. Unlike sinkholes, losing streams have no distinct topographic expression that can be identified from topographic maps. They must be identified by field observation using discharge, flow duration, vegetation, channel configuration, drainage basin size, sediment size and sorting, and other factors as indicators. As part of this study, a hydrologic reconnaissance was conducted throughout the study area to identify losing streams and losing-stream reaches. All road crossings of all streams in the area were visited. Reaches of many losing streams were walked to determine more exact points of water loss, and to search for potential dye tracing injection sites. Flow conditions, texture of alluvial materials, bedrock conditions, and vegetative indicators were noted. Dozens of losing streams were identified, ranging from relatively small watersheds to basins containing many square miles of drainage. Existing data from seepage runs conducted by the U. S. Geological Survey were also used to determine losing-stream segments. A seepage run consists of a series of discharge measurements taken along a stream reach during a short time period, typically when the stream is under low-flow conditions. Downstream discharge decreases indicate losing-stream conditions; downstream flow increases indicate gaining-stream conditions.

Figure 3 shows the losing and gaining streams identified in the study area. It also shows stream segments that are perennial but which have significant flow loss. Table 1 lists streams in the study area, their drainage areas, and the drainage areas upstream of losing segments.

There are far more streams in the study area that contain losing reaches than streams which gain throughout their lengths. Even most of the streams that are primarily gaining contain losing reaches in the upper watershed areas where the water table is below valley bottom. Some of the streams have definite gaining and losing reaches. Bear Creek, for example, contains a losing reach in the upper part of the watershed, a gaining reach in the middle section of the watershed, and another losing reach in the lower part of the water-

The Hydrogeology of the Bennett Spring Area

shed. All of Bear Creek upstream of the farthest downstream losing reach is considered losing. Even though it contains a gaining reach, flow along the gaining-stream reach eventually flows into the subsurface before reaching the Gasconade River. Jones Creek contains gaining

reaches in the upper and lower parts of the watershed, with a losing reach in between. Several creeks, such as Dousinbury Creek, Brush Creek, and North Cobb Creek, lose flow in the upper parts of their watershed and are gaining streams in their downstream reaches.

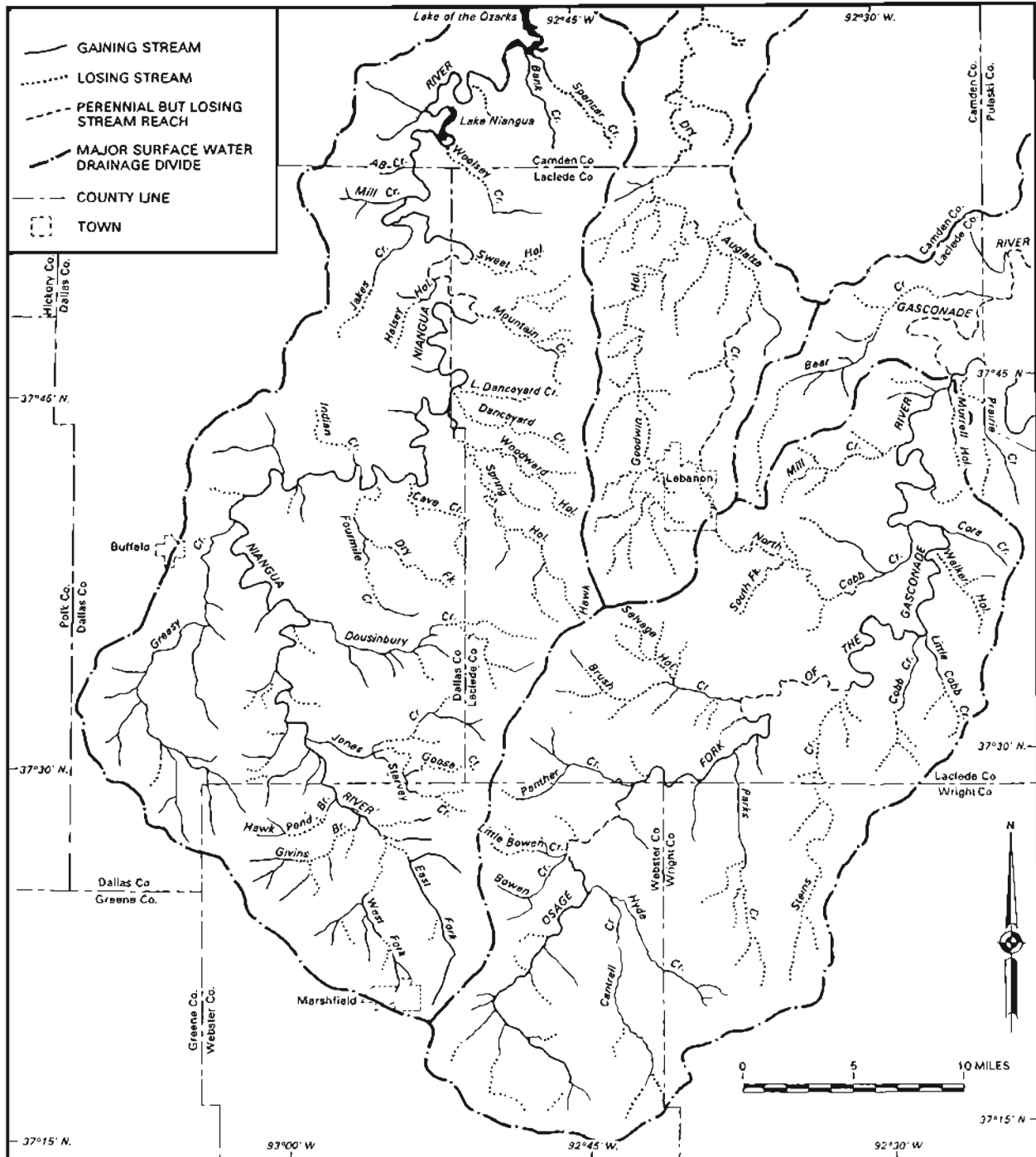


Figure 3: Gaining and losing streams in the Bennett Spring study area.

STREAM NAME	TOTAL WATERSHED AREA (MI ²)	LOSING WATERSHED * AREA (MI ²)
NIANGUA RIVER BASIN		
Woolsey Creek	19.8	19.8
AB Creek	3.9	G
Mill Creek	10.5	G
Jakes Creek	26.7	G
Sweet Hollow	8.0	8.0
Halsey Hollow	5.2	2.6
Mountain Creek	27.0	27.0
Little Danceyard Creek	7.9	7.9
Danceyard Creek	8.9	8.9
Spring Hollow (above Bennett Spring)**	42.5	42.5
Woodward Hollow	9.2	9.2
Cave Creek	13.3	13.3
Fourmile Creek**	27.5	27.5
Dry Fork	6.5	6.5
Indian Creek	7.4	4.8
Durington Creek	10.5	G
Greasy Creek	71.6	G
Dousinbury Creek	41.8	23.2
Jones Creek**	34.3	28.6
Starvey Creek**	13.3	12.2
Goose Creek	3.5	3.0
Hawk Pond Branch	5.8	5.3
Givins Branch	20.0	18.7
Hollis Branch	2.2	2.2
East Fork Niangua River**	25.6	25.6
Sarah Branch	5.0	G
West Fork Niangua River**	27.9	27.9
Greer Creek	10.6	3.1
GRANDGLAIZE CREEK BASIN		
Dry Auglaize Creek**	205.8	196.8
Goodwin Hollow	72.1	72.1
OSAGE FORK BASIN		
Murrell Hollow	3.7	3.2
Mill Creek	16.3	16.3
North Cobb Creek**	53.3	38.8
South Fork	14.9	14.9
Core Creek	7.7	NA
Walker Hollow	9.1	9.1
Little Cobb Creek	12.0	4.1
Cobb Creek	17.9	12.0
Steins Creek	44.5	44.5
Brush Creek**	42.2	37.9
Selvage Hollow	10.4	10.2
Parks Creek	35.4	24.5
Panther Creek	22.5	1.7
Little Bowen Creek	8.2	5.3
Bowen Creek	9.1	2.5
Cantrell Creek**	59.8	G
Hyde Creek	23.6	G
GASCONADE RIVER BASIN		
Bear Creek	43.7	38.6
Prairie Creek	13.5	12.8

* Includes all drainage upstream of farthest downstream losing reach.

** Drainage area and losing-stream watershed area include tributaries.

NA Data not available.

G Gaining stream, but watershed may contain minor water-loss zones in upstream reaches.

Note: Tributaries above are shown indented beneath receiving stream.

Table 1: Hydrologic data for streams in the Bennett Spring study area.

Several creeks are losing streams essentially from headwaters to mouth, and are dry except for short periods following major rainstorms. Spring Hollow upstream from Bennett Spring, Goodwin Hollow, Steins Creek, and Cave Creek are included in this group. In very few places do these creeks or their tributaries carry flow in dry weather. Dry Auglaize Creek also loses flow throughout most of its length. However, because of the volume of wastewater introduced into the stream, it is generally perennial downstream for several miles from the Lebanon wastewater treatment plant.

FLOW CHARACTERISTICS OF MAJOR STREAMS IN THE BENNETT SPRING AREA

Very few streams in the study area which are gaining streams have perennial flow. Major streams like the Niangua River, the Osage Fork of the Gasconade River, and Gasconade River are perennial, but all three contain water-loss zones along their reaches. The East and West Forks of the Niangua River both contain losing zones with perennial flow upstream and downstream from them. Low-flow measurements by the U.S. Geological Survey show a water-loss zone in the Niangua River between Mountain Creek and Sweet Hollow. Measurements also show water-loss zones in the Osage Fork between Bowen Creek and Panther Creek, and between Big Spring and Orla. The Gasconade River loses flow for several miles downstream from the Osage Fork confluence.

Only a few tributaries of these rivers contribute appreciable flow to the rivers during dry weather. During periods of low base-flow, only about 4 percent of the flow in the Niangua River throughout its reach is from tributary contributions. About 68 percent of the flow is from known springs with the remaining 28 percent from general groundwater inflow (Harvey et al., 1983). The Jones Creek, Dousinbury Creek, Greasy Creek, Halsey Hollow, Jakes Creek, and Mill Creek tributaries also contribute appreciable flow to the Niangua River.

The Osage Fork receives about 11 percent of its flow during low base-flow conditions from tributary contributions. About 61 percent of its flow is from known springs with 28 percent from general groundwater inflow (Harvey et al., 1983). The Osage Fork has more tributaries which contribute flow than the Niangua; they include Cantrell Creek,

Hyde Creek, Bowen Creek, Panther Creek, Parks Creek, Brush Creek, Cobb Creek, Little Cobb Creek, North Cobb Creek, and Core Creek.

The Gasconade River in the study area, and upstream from the Osage Fork confluence, receives little contribution from tributaries during low base-flow periods. About 47 percent of its flow comes from known springs, and the remaining 53 percent is from general groundwater inflow (Harvey et al., 1983). Goodwin Hollow and Dry Auglaize Creek are Grand Glaize Creek tributaries; both are losing streams and except for the very downstream part of Dry Auglaize Creek, contribute no flow to the Grand Glaize during low base-flow periods.

Average annual runoff data for major rivers can be an important indicator of subsurface movement of groundwater into or out of a surface watershed. However, since river basin sizes vary, discharge volumes must be corrected for drainage area size to determine the watershed inches of runoff from a basin. A watershed inch is the volume of water necessary to cover the entire topographic drainage basin to a depth of 1 inch. If the river gaging stations are downstream of springs, then the discharge of the springs, as well as surface-water runoff and diffused groundwater inflow into the streams, are included in the runoff figures. Average annual runoff values that are significantly above regional averages in the Ozarks are usually due to groundwater inflow from outside of the basin. Conversely, average annual runoff values that are significantly below regional averages are usually due to groundwater leaving the basin to recharge a spring outside of the topographic watershed.

Long-term flow data are available from U.S. Geological Survey gaging stations on the Niangua River, Osage Fork, and Gasconade River. The Niangua River upstream from Tunnel Dam, about 8 miles northwest of Decaturville, has a drainage area of 627 mi² and an average annual runoff of 13.5 watershed inches. This amount is about 2.5 inches greater than the average regional runoff. The Osage Fork at Dryknob, with a drainage area of 404 mi², has an average annual runoff of 9.55 watershed inches. This is about 2.5 inches less than average regional runoff. The Gasconade River near Hazelgreen, which includes the Osage Fork, has a drainage area of about 1,250 mi² and

an average annual runoff of 10.5 inches per year. This is about 1.5 inches less than the regional average. These figures indicate that groundwater is lost from both the Osage Fork and Gasconade River basins upstream from the gaging stations, while the Niangua River basin receives groundwater from outside of the basin.

FLOW CHARACTERISTICS OF LOSING STREAMS IN THE BENNETT SPRING AREA

Continuous flow-measurement data are not commonly available for many smaller gaining-stream watersheds, and almost never available for losing-stream watersheds. It is well known that even losing streams with very high water-loss rates carry flow after heavy precipitation. To help quantify water-loss rates in losing-stream watersheds in the Bennett Spring area and better understand their flow characteristics, instruments to measure stage height were installed on three major losing streams. The gaging installations used pressure transducers and dataloggers to measure and record flow events occurring on these streams. Additionally, precipitation data were collected to correlate runoff volumes with rainfall amounts.

There are three long-term U.S. Weather Service observation stations in the study area. They are near Lebanon, Buffalo, and Marshfield, and collect daily temperature and precipitation data. The Missouri Department of Conservation at Lebanon also measures and records daily precipitation. There are commonly significant temporal and spatial variations in precipitation. Rainfall amounts from a single storm event can vary greatly over short distances, so for this study additional precipitation stations were established to supplement data from existing precipitation observation stations. Non-recording rain gages were installed at the homes of nine people who volunteered to measure and record daily rainfall during the study. Several of the stations were installed near the beginning of the study, and collected precipitation data throughout water year 1989-1990. Other stations were established later in locations where needed.

Precipitation data collected by National Weather Service observers and the volunteers is reported as daily rainfall. However, rain gages are not typically read at midnight, so the reported daily

rainfall is that which occurred during the 24-hour period between the times the rain gage is normally read. In many aspects, daily rainfall data are quite adequate, but they do not accurately reflect rainfall intensity. Three inches of rainfall will generate significant runoff if it occurs during a two-hour period, but may produce little runoff if it occurs during a 24-hour period.

Rainfall intensity data were collected by installing a continuously-operating recording rain gage at the Bob Russell farm in the central part of the study area. This installation consists of a tipping-bucket rain gage and event recorder placed in a heated enclosure (photo 2). Precipitation enters the tipping-bucket rain gage through an 8.2-inch diameter cylinder (photo 3), and is then funneled through its base into one of two tipping buckets. When the bucket is full, which is after 0.01 inch of precipitation, its weight causes it to tip and bring the second bucket into position to collect the precipitation (photo 4). Simultaneously, a reed switch closes sending a brief electrical impulse to the event recorder. Water in the first bucket empties through the bottom of the rain gage, and out the bottom of the enclosure. The process repeats each time one of the buckets is full. The gage is accurate to within 0.5 percent at a precipitation rate of 0.5 inches per hour.

The event recorder consists of a rotating drum and pen arm (photo 5). The drum is moved by a quartz clock at a rate of one revolution each 31 days. Each .01 inch of precipitation causes the rain gage to send an electrical impulse to the event recorder and energizes a solenoid. The solenoid drives a ratchet, causing the pen arm to move upward a small amount. The pen movement is recorded on a calibrated paper chart attached to the recorder drum. After 100 cycles, which is 1 inch of precipitation, the arm falls back to the base of the drum. During cold weather, a thermostat-controlled heat source in the insulated enclosure provides enough heat to melt snow entering the rain gage, allowing frozen precipitation to be measured.

The locations of weather observation stations in the study area are shown in figure 4. Daily precipitation data for each station for water year 1989-1990 is shown in tables 2-15. Shown below each table in figures 5-18 are bar-graph plots of daily precipitation. Of the six stations where data

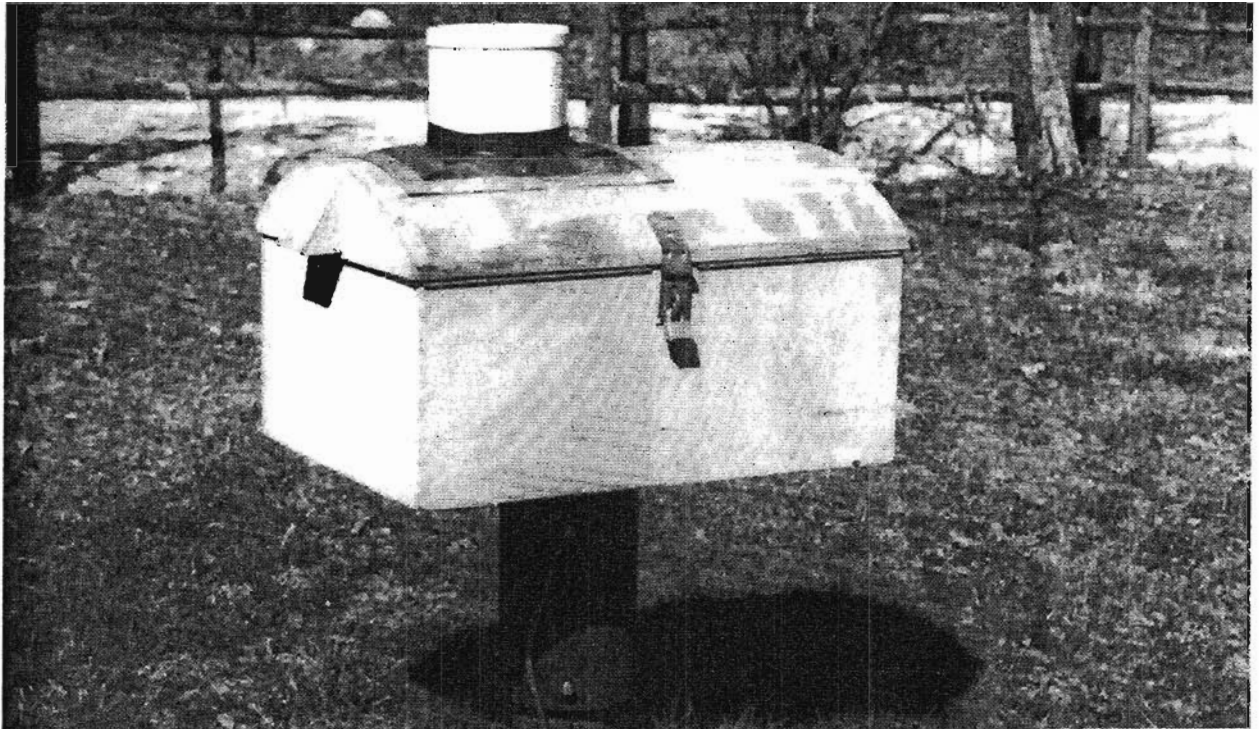
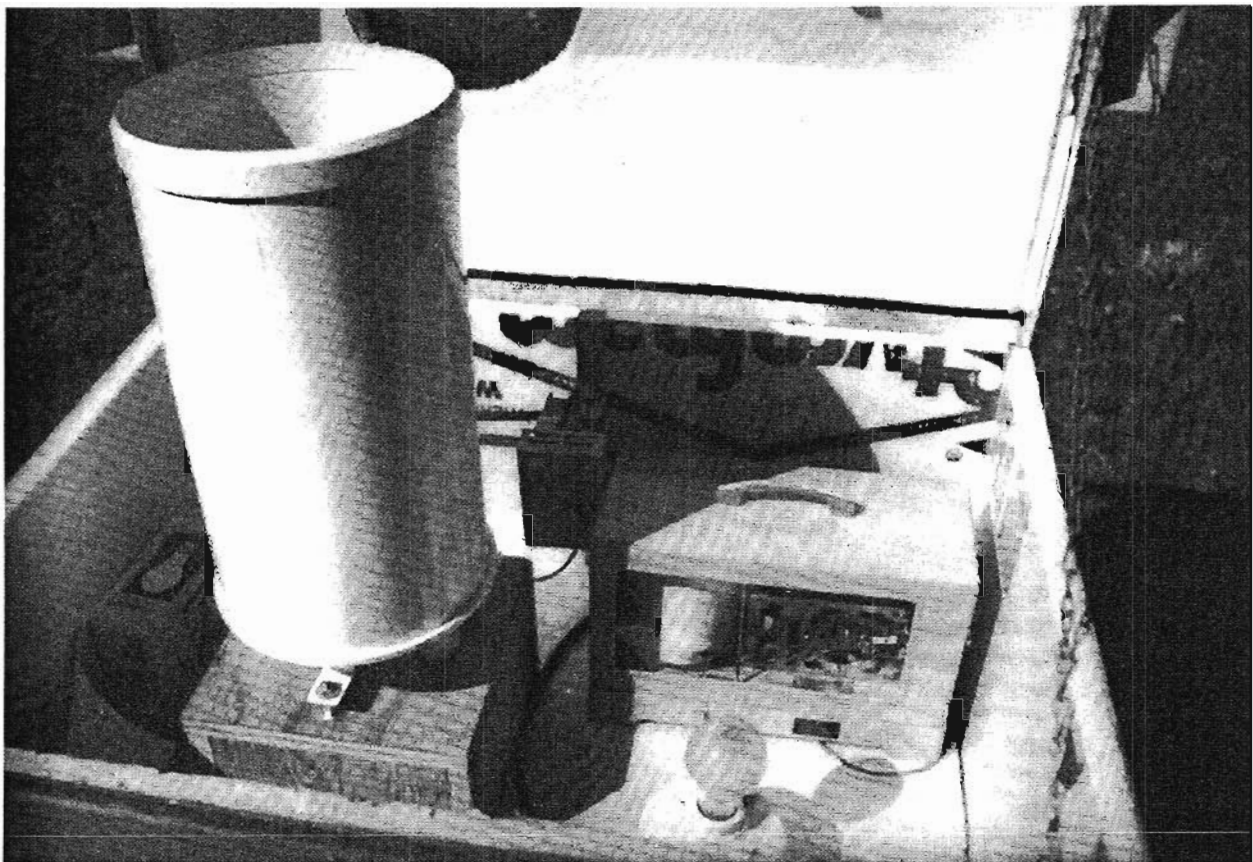


Photo 2. (Above) A recording rain gage installation in Spring Hollow collects precipitation data.

Photo 3. (Below) Precipitation enters the tipping-bucket rain gage through its cylindrical housing, and is funneled into the bucket.



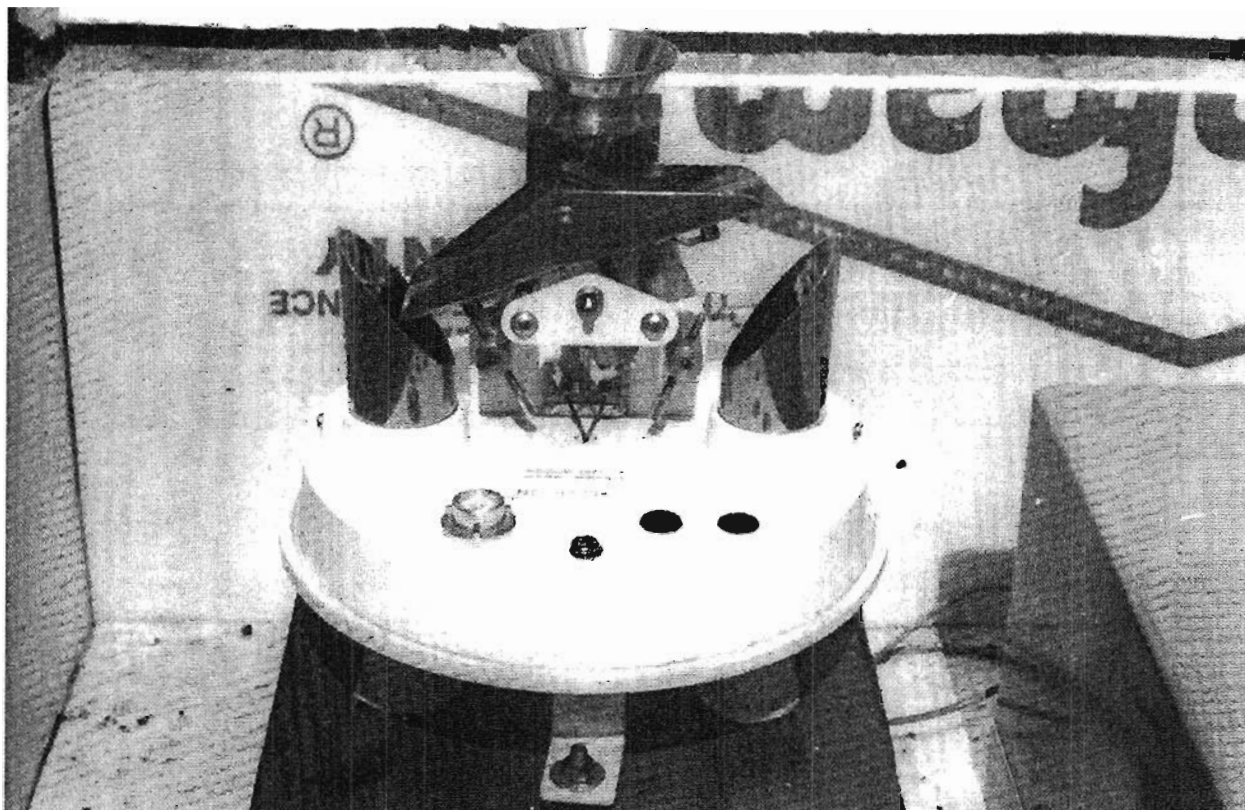
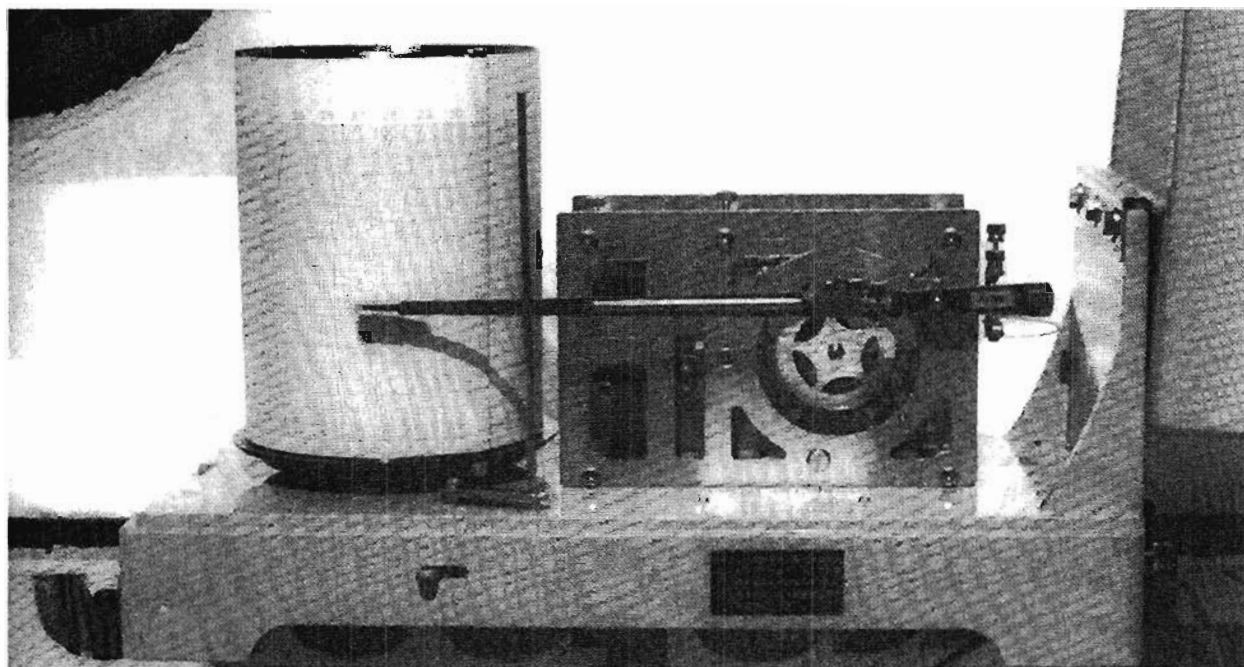


Photo 4. (Above) The weight of water from each .01 inch of rain causes the bucket to tip, which empties the full bucket through the bottom of the gage, and brings the empty bucket into position beneath the funnel.

Photo 5. (Below) Each time the bucket empties, a signal is sent to the event recorder which causes the pen arm to move upward. A felt-tip pen leaves a trace of the movement on the paper. After each inch of precipitation, the pen arm returns to the bottom of the drum and begins moving upward again. The drum on the event recorder rotates once each 31 days.



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are available for the entire water year, Buffalo 3S reported the highest precipitation, 52.14 inches. Lebanon 2W and Missouri Department of Conservation-Lebanon reported 50.56 inches and 50.85 inches, respectively. For most of the stations, the wettest months were March, May, and July, and the driest were October and December. Average rainfall in the area for water years 1956 through 1990 is about 41 inches, making water year 1989-1990 one of the wetter years. The highest annual precipitation for the Lebanon area occurred during calen-

dar year 1927, when total precipitation measured 74.20 inches (John Fowler, 1991, personal communication).

Precipitation during calendar year 1989 was considerably less than normal. Buffalo 3S and Marshfield stations reported 28.53 inches and 31.28 inches, respectively. Lebanon 2W reported 24.96 inches, with data from January missing. Missouri Department of Conservation-Lebanon reported 32.90 inches of precipitation.

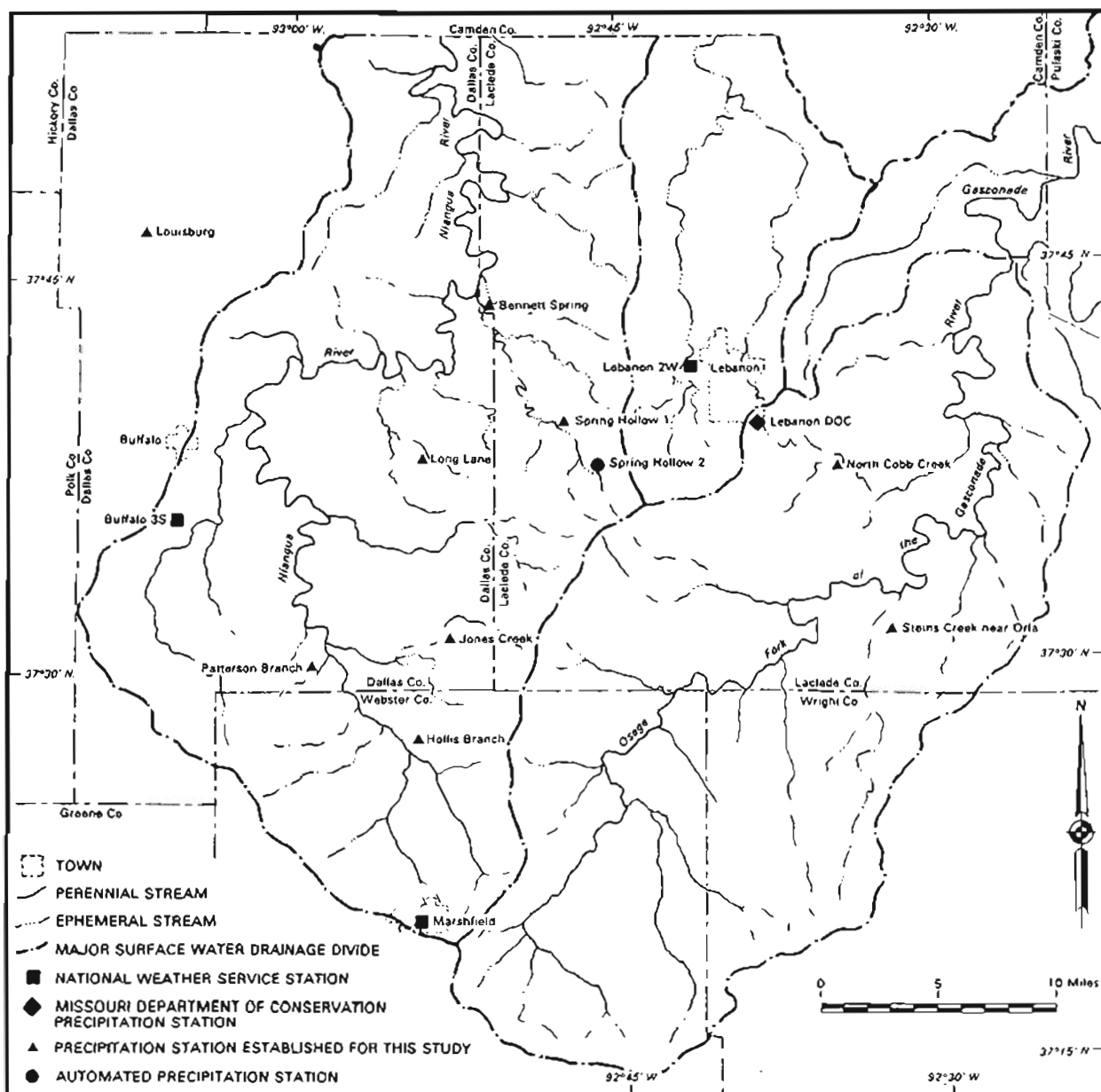


Figure 4: Locations of weather observation stations in the Bennett Spring area.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE LEBANON 2W WEATHER OBSERVATION STATION

LACLEDE COUNTY, SW1/4 SE1/4 SEC. 4, T. 34 N., R. 16 W.

37 DEG 41 MIN 08 SEC NORTH LATITUDE, 92 DEG 41 MIN 37 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 1250 FEET ABOVE MEAN SEA LEVEL

WEATHER OBSERVER: JOHN FOWLER-RADIO STATION KIRK-KJEL

TIME GAGE IS READ : 7:00 AM

INSTALLATION OPERATED BY: NATIONAL WEATHER SERVICE

TYPE OF INSTALLATION: NWS NON-RECORDING RAIN GAGE

STATION INSTALLED 1887, 103 YEARS OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.19	0.33	....	....	0.13	....	....	....
2	0.82	....	....	0.01	....	....	....	....
3	0.23	0.10	....	....	1.77	....	....	....	....
4	0.47	....	....	0.79	....	....	1.80	....
5	0.06	....	....	....	....	0.93	....
6	0.62	....	....	....	0.14	0.18	0.46	....	....	....	....	....
7	0.03	0.24	....	....	....	0.07	....	....
8	0.49	....	....	....	....	....	0.20
9	0.20	....	....	....	0.52	....	....	....
10	1.37	0.17	0.04	....	....	....
11	0.16	....	....	....	0.08	0.97
12	0.55	....	0.67	....	0.75	0.33	....
13	0.05	0.25	....	1.14	....	....
14	2.04	....	....	....	0.92	0.54	....	....	0.06	....	....
15	1.28	0.33	....	0.93	1.83	....	0.64	0.62	....	....	....
16	0.62	....	....	1.28	0.70	....	0.10	0.40	....	....	0.29	....
17	0.52	....	....	0.23	0.39	....	....	0.02	....
18
19	1.41	....	0.17	....	....	0.07	....	....	0.69
20	0.14	....	....	....	0.07	....
21	0.52	....	0.06	1.18	0.45	....	....	0.20
22	0.22	....	....	0.19	0.11	....	....	0.52	1.03	....	0.37
23
24	0.72	....	....	....	....	....	....
25	0.11	....	....	....	....	....	....	....	....
26	0.04	....	....	3.90	0.46	0.17	....	....
27	0.03	0.28	0.02	3.83	....	....
28	0.19	0.40	0.55	....	....	....	....	....
29	0.63	....	....	0.03	....	....	....	....	....	....
30	0.24	....	....	....	....	0.14	0.13	....	....	....	....	0.02
31	0.15	....	0.07	....	....	....	....
MONTHLY TOTALS	1.48	3.54	0.96	3.55	4.52	6.32	3.82	10.52	2.83	7.05	3.52	2.45

TOTAL PRECIPITATION: 50.56 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 95

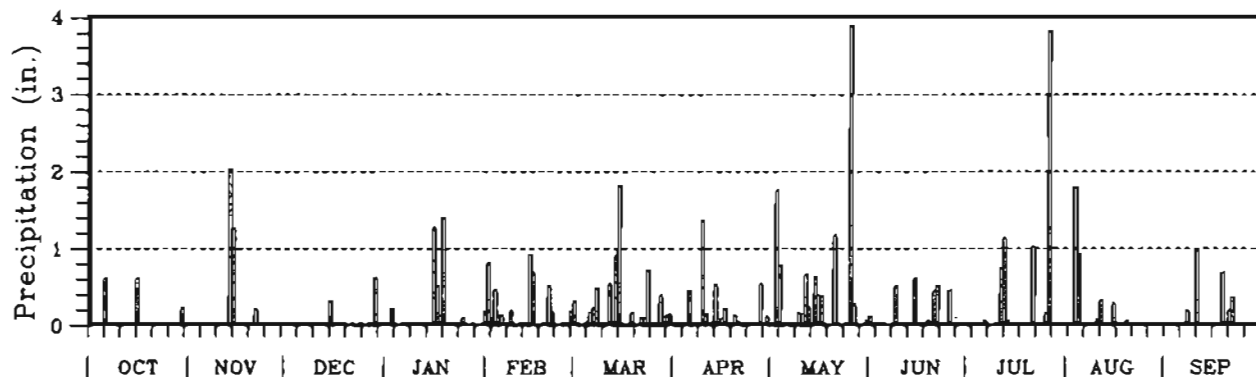


Table 2 and Figure 5: Daily precipitation, Lebanon 2W weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE MARSHFIELD WEATHER OBSERVATION STATION

WEBSTER COUNTY, NW1/4 NW1/4 SEC. 10, T. 30 N., R. 18 W.
 37 DEG 20 MIN 17 SEC NORTH LATITUDE, 92 DEG 54 MIN 31 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1490 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: ED TERRY TIME GAGE IS READ: 7:00 AM
 INSTALLATION OPERATED BY: NATIONAL WEATHER SERVICE
 TYPE OF INSTALLATION: NWS NON-RECORDING RAIN GAGE
 STATION INSTALLED 1941, 49 YEARS OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.20	0.34	....	0.08	0.10	....	....	....
2	0.76	....	....	0.02	....	....	....	....
3	1.85	....	....	....	....
4	0.48	0.56	....	....	0.46	....	....	....	....
5	0.19	....
6	0.05	....	....	....	0.13	0.18	....	....	....	....	....	....
7	0.57	....	....	....	0.06	0.55	....	....	....	....	....	....
8	0.38	....	....	0.34	....	....	0.03	....	....	0.30
9	0.74	....	....	....	0.89	....	....	....
10	1.25	0.04	0.03	....	....	....
11	0.10	....	....	0.12	....	0.54
12	0.74	....	0.76	....	0.72	....	....
13	0.28	....	1.21	0.10	....
14	0.08	....	....	....	0.37	0.40	....	....	....	....	....
15	0.05	....	1.15	1.97	0.10	0.90	0.33	0.18	....	....
16	0.83	....	0.06	1.29	0.02	....	0.61	....
17	1.81	....	....	0.73	1.46	....	....	0.02	....
18	0.21	....	....	....	....	....	....	....	0.03
19	0.03	....	....	0.06	....	0.09	0.46	....	....	0.57
20	2.03	....	....	0.23	0.58	....	....	0.08	....
21	0.08	1.02	0.36	....	....	0.45
22	0.27	....	....	0.38	....	....	0.02	1.38	0.35	....	1.68
23	0.18	....	....	....	....	....	....	....
24	0.02	....	....	1.23	....	....	....	....	....	....
25	0.11	....	....	....	....	....	....	....	....
26	0.97	0.23	0.16	....	....
27	0.05	1.22	0.27	1.23	....	....
28	0.22	0.58	0.38	0.05	....	....	....	....
29	0.28	....	....	0.10	....	....	....	....	....	....
30	0.22	....	....	....	....	0.24	....	....	....	....	....	....
31	0.08	....	0.36	....	....	....	....
MONTHLY TOTALS	0.84	0.35	0.76	4.64	5.21	6.78	3.38	11.45	4.10	3.97	1.00	3.57

TOTAL PRECIPITATION: 46.05 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 96

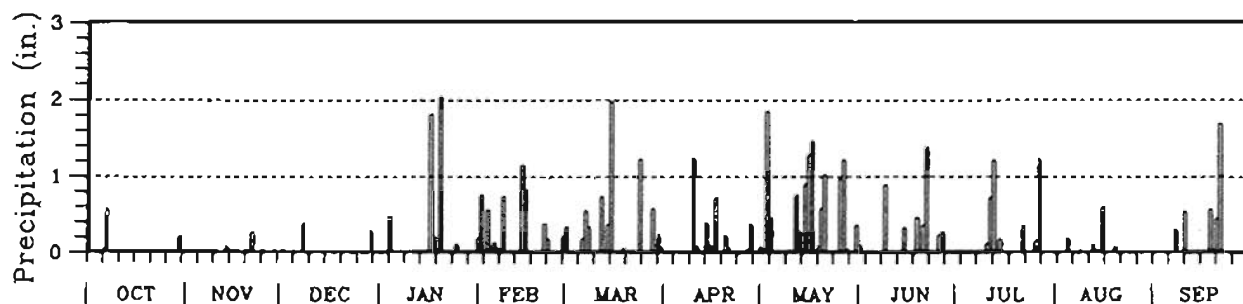


Table 3 and Figure 6: Daily precipitation, Marshfield weather observation station.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE BUFFALO 3S WEATHER OBSERVATION STATION

DALLAS COUNTY, NE1/4 SW1/4 SEC. 11, T. 33 N., R. 20 W.
 37 DEG 35 MIN 37 SEC NORTH LATITUDE, 93 DEG 05 MIN 59 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1150 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: MRS. LOLAN HOWERTON TIME GAGE IS READ: 7:00 AM
 INSTALLATION OPERATED BY: NATIONAL WEATHER SERVICE
 TYPE OF INSTALLATION: NWS NON-RECORDING RAIN GAGE
 STATION INSTALLED 1931, 59 YEARS OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.15	0.32	0.01	0.04	0.26	....	....	....
2	0.55	....	....	0.02	0.02	....	....	....
3	1.51	....	....	0.41	....
4	0.52	0.55	....	....	0.87	....	....	1.23	....
5	0.05	....	....	....	....	0.20	....
6	0.50	....	....	....	0.06	0.20	0.46	0.12	....	....	....	....
7	0.23	....	....	....	....	0.24	....	....	....	....	....	....
8	0.20	....	....	0.45	....	....	....	....	....	0.06
9	0.15	....	....	....	0.52	....	....	....
10	1.40	0.13	0.15	....	....	....
11	0.13	....	....	0.62	....	1.64
12	0.58	....	0.70	....	1.19	0.05	....
13	1.66	0.79	0.67
14	0.54	....	....	....	2.35	0.70	....	....	....	....	....
15	0.06	0.21	....	0.90	1.97	0.06	0.74	0.88	0.24	....	....
16	0.71	....	....	0.72	....	....	1.12	....
17	1.09	....	....	0.72	0.33	....	....	....	....
18	0.15	....	....	....	....	....	....	....	0.50
19	0.06	....	....	0.08	....	0.04	0.60	....	....	0.91
20	0.70	....	....	0.09	0.60	....	....	1.13	....
21	1.02	0.74	....	....	0.45
22	0.12	....	....	0.64	0.04	....	....	0.60	0.56	....	0.20
23	0.32	....	....	....	....	....	....	....
24	0.82	....	....	....	....	....	....
25	0.04	....	0.04	....	....	....	....	....	....
26	4.30	0.67	0.31	....	....
27	0.07	....	0.08	0.71	0.17	0.20	....	....
28	0.20	0.45	0.28	0.10	....	....	....	....
29	0.26	....	....	0.07	....	....	....	....	....	....
30	0.23	....	....	....	....	....	....	....	....	....	....	0.14
31	0.08	....	....	....	....	0.16	....	0.26	....	....	....	....
MONTHLY TOTALS	1.04	0.72	0.73	2.50	4.30	7.82	3.93	12.21	4.61	4.78	4.93	4.57

TOTAL PRECIPITATION: 52.14 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 101

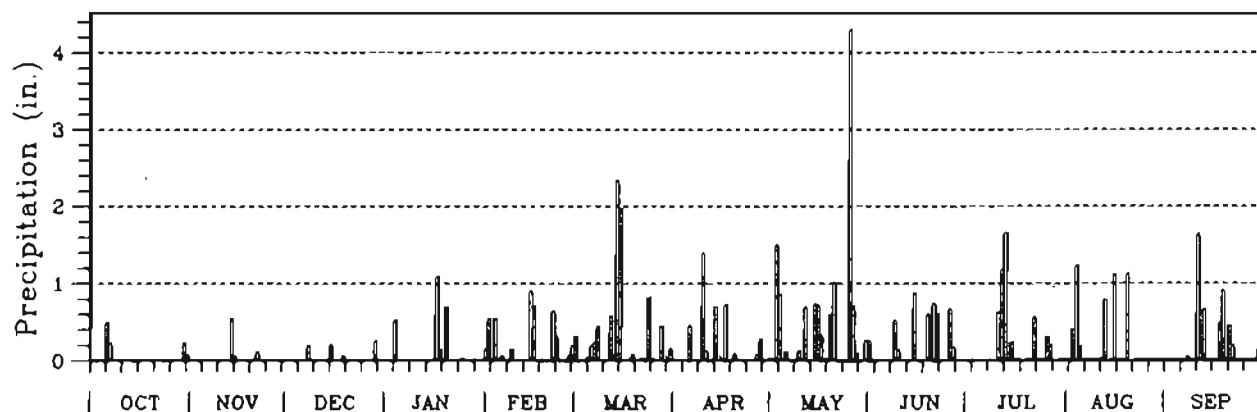


Table 4 and Figure 7: Daily precipitation, Buffalo 3S weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE MISSOURI DEPT. OF CONSERVATION-LEBANON WEATHER OBSERVATION STATION

LACLEDE COUNTY, SW1/4 NW1/4 SEC. 24, T. 34 N., R. 16 W.

37 DEG 38 MIN 53 SEC NORTH LATITUDE, 92 DEG 38 MIN 55 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 1310 FEET ABOVE MEAN SEA LEVEL

WEATHER OBSERVER: JACKIE CLARK

TIME GAGE IS READ: 1:00 PM

INSTALLATION OPERATED BY: MISSOURI DEPARTMENT OF CONSERVATION

TYPE OF INSTALLATION: B-INCH NON-RECORDING RAIN GAGE

STATION INSTALLED: DATE UNKNOWN

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.19	....	0.02	0.21	....	....	....	....
2	0.03	0.44	....	....	....	....	....	....	....
3	0.53	0.29	....	....	2.18	....	....	....	....
4	0.58	....	....	0.46	....	....	1.53	....
5	0.55	....	....	0.12	....	....	....	....	0.25	....
6	0.57	....	....	....	0.09	0.10	0.46	0.07	....	....	....	0.68
7	0.58	....	....	....	....	....	....
8	0.30	....	....	....	....	....	0.02
9	0.34	....	....	....	0.53	....	....	....
10	1.29	....	....	....	....	....
11	1.17	0.02	0.33
12	0.66	....	1.13	....	0.27	....	0.17
13	0.41	....	....	1.04	1.00	....
14	2.21	....	....	0.05	0.89	0.34	0.03	0.50	....	....	....
15	1.02	0.12	....	1.84	1.77	0.14	0.58	....	....	0.28	....
16	0.07	....	....	....	....	....	0.74	....	....	....	....
17	0.05	....	....	2.03	....	....	0.24	0.54	....	....	0.03	....
18	0.01	....	....	0.13	....	....	....	0.01	....	0.57
19	0.73	....	....	....	0.52	0.10	....	....	....
20	0.07	....	0.88	....	....	0.22	....	0.40	....	0.02	....
21	0.58	....	0.04	0.79	....	0.03	....	0.56
22	0.28	....	....	0.06	0.05	....	....	0.58	....	....	....
23	0.16	....	....	....	....	....	....	....
24
25	0.28	....	....	....	....	0.44	0.25	....	....
26	0.64	....	5.31	....	2.03	....	....
27	0.06	....	0.18	0.23	....	....	....	....
28	0.38	0.47	0.40	....	....	....	....	....
29	0.39	....	....	....	....	....	....	....	....	....
30	0.30	....	....	....	....	....	....	....	....	....	....	0.01
31	0.24	....	....	....	0.37	....	....	....	....
MONTHLY TOTALS	0.92	3.65	1.07	4.72	5.06	5.71	3.74	13.16	2.55	4.80	3.13	2.34

TOTAL PRECIPITATION: 50.85 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 95

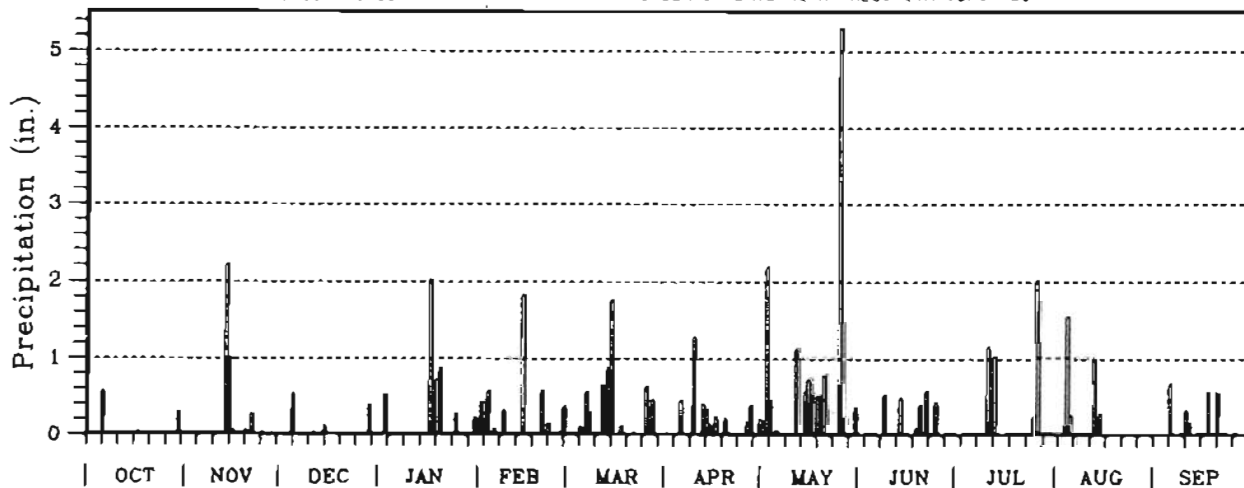


Table 5 and Figure 8: Daily precipitation, Missouri Department of Conservation-Lebanon weather observation station.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE BENNETT SPRING WEATHER OBSERVATION STATION

LACLEDE COUNTY, SE1/4 SW1/4 SEC. 31, T. 35 N., R. 17 W.
 37 DEG 43 MIN 17 SEC NORTH LATITUDE, 92 DEG 51 MIN 18 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 890 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: DIANE TUCKER TIME GAGE IS READ: 5:00 PM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED OCT 6, 1989, 1 YEAR OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	....	....	....	0.79	....	....	0.08	0.03	....	....	....
2	****	....	....	....	....	....	....	0.01	....	....	....	....
3	****	....	....	0.44	0.15	....	0.04	1.55	....	....	0.52	....
4	****	....	....	0.18	0.50	....	....	0.70	....	....	1.17	....
5	****	....	....	....	....	0.06	0.41	....	....	0.07	....	....
6	....	....	....	....	0.05	0.42	....	....	....	....	....	....
7	....	....	....	....	....	0.34	....	....	....	....	....	0.22
8	....	....	0.30	....	....	0.50	....	....	0.66	....	....	0.02
9	....	....	....	....	0.32	....	....	0.11	....	....	....	....
10	....	....	....	....	....	....	1.43	....	0.01	....	....	0.80
11	....	....	....	....	....	0.07	....	0.01	....	1.95	0.35	....
12	....	....	....	....	....	....	....	0.98	....	0.03	0.08	....
13	....	....	....	....	0.31	....	0.63	....	....	2.22	0.03	....
14	....	1.45	....	....	1.32	3.35	0.20	....	1.30	0.02	....	....
15	....	0.06	0.26	....	0.02	1.30	0.15	....	0.01	....	0.41	....
16	....	0.05	....	0.06	....	....	....	1.65	....	....	0.12	....
17	....	....	0.02	1.07	....	....	0.26	0.02	....	....	0.05	....
18	....	....	....	....	....	0.20	....	....	....	....	....	0.80
19	....	....	0.05	1.50	....	0.03	....	....	....	....	0.15	....
20	....	....	....	0.02	....	....	0.09	....	0.74	....	0.22	0.05
21	....	....	....	....	....	....	....	....	0.44	....	....	0.52
22	....	0.15	....	....	0.74	0.06	....	....	....	....	0.01	....
23	....	....	....	....	0.16	....	....	....	....	0.46	....	....
24	....	....	....	0.08	....	0.64	....	0.76	....	....	....	....
25	....	....	....	0.08	....	....	0.04	2.80	0.38	0.04	....	....
26	....	....	....	....	....	....	....	....	0.02	0.67	....	....
27	....	....	....	....	0.11	....	0.54	0.20	0.01	0.02	....	....
28	....	....	....	....	0.30	....	0.52	0.32	0.01	....	....	....
29	....	....	0.40	....	....	0.08	0.01	....	....	....	....	....
30	0.22	....	....	....	....	0.20	....	0.05	....	....	....	0.06
31	....	....	....	....	....	....	....	0.20	....	....	....	....
MONTHLY TOTALS	0.22	1.71	1.03	3.43	4.77	7.77	4.12	9.13	3.60	5.48	3.11	2.47

TOTAL PRECIPITATION: 46.84 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 108

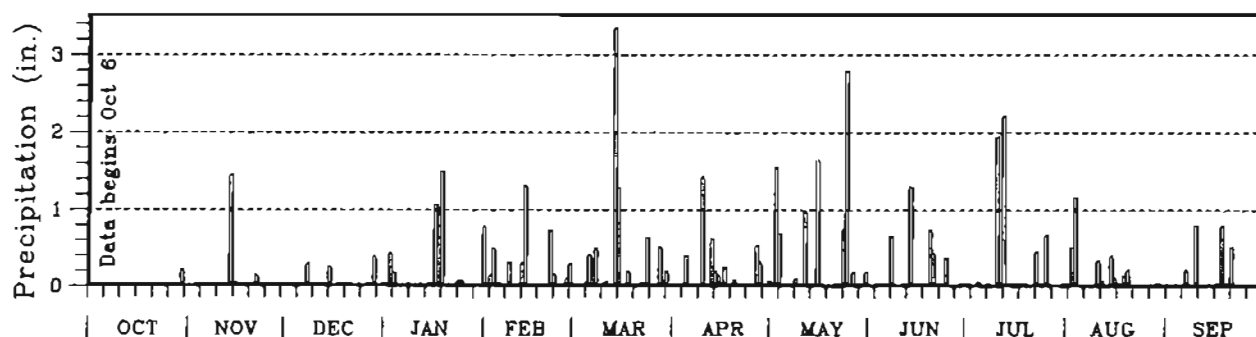


Table 6 and Figure 9: Daily precipitation, Bennett Spring weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE SPRING HOLLOW #1 WEATHER OBSERVATION STATION

LACLEDE COUNTY, SW1/4 NW1/4 SEC. 22, T. 34 N., R. 17 W.
 37 DEG 39 MIN 09 SEC NORTH LATITUDE, 92 DEG 47 MIN 48 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1220 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: MARK KING TIME GAGE IS READ: 8:00 AM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED OCT 6, 1989, 1 YEAR OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	....	....	....	0.14	0.10	....	0.07	0.21	....	....	....
2	****	....	....	....	0.69	....	....	0.02	0.08	....	....	....
3	****	....	....	....	****	....	....	1.65	....	....	....	....
4	****	....	....	....	0.34	....	....	0.51	....	....	2.00	....
5	****	....	....	....	****	0.08	....	0.01	....	....	0.40	....
6	....	....	....	....	0.11	0.17	0.46	0.06	....	....	....	....
7	....	0.17	....	....	0.05	0.32	....	....	....	....	....	....
8	....	....	....	....	....	0.42	....	....	....	....	....	....
9	....	....	....	....	0.21	....	....	0.09	0.52	....	....	....
10	....	....	....	....	....	....	1.52	....	0.02	....	....	....
11	....	....	....	....	....	....	0.02	....	....	1.68	....	0.36
12	....	....	....	....	....	0.48	....	0.94	....	0.21	0.04	0.09
13	....	....	....	....	....	....	0.18	0.03	....	1.13	0.65	0.02
14	....	0.87	....	....	0.01	1.02	0.46	....	....	....	....	....
15	....	0.50	....	....	1.30	2.05	0.12	0.70	0.90	....	....	....
16	....	0.03	....	....	0.29	....	....	0.86	....	....	0.38	....
17	0.05	....	....	1.05	....	....	0.25	0.05	....	....	0.01	....
18	....	....	....	0.32	....	....	....	....	....	....	....	0.16
19	....	....	....	....	....	0.15	....	0.79	0.08	....	....	0.68
20	....	....	....	1.45	....	....	0.16	0.02	0.50	....	0.48	....
21	....	....	....	....	....	....	....	0.70	0.03	....	....	0.47
22	....	....	....	....	0.50	0.04	....	....	0.51	0.41	....	0.12
23	....	....	....	....	0.16	....	....	....	....	....	....	....
24	....	....	....	....	....	0.15	....	....	....	....	....	....
25	....	....	....	0.15	....	....	....	0.02	....	0.05	....	....
26	....	....	....	....	....	....	0.02	4.10	0.28	1.75	....	....
27	....	....	....	....	0.03	....	0.28	0.24	0.03	0.02	....	....
28	....	....	....	....	0.20	0.44	0.55	0.03	....	....	....	....
29	....	....	....	....	....	0.03	....	....	....	....	....	....
30	0.28	....	....	....	....	0.18	....	....	....	....	....	....
31	0.05	....	....	....	....	0.07	....	0.08	....	....	....	....

MONTHLY TOTALS 0.38 1.57 0.00 2.97 4.03 5.70 4.02 10.97 3.16 5.25 3.96 1.90

TOTAL PRECIPITATION: 43.91 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 102

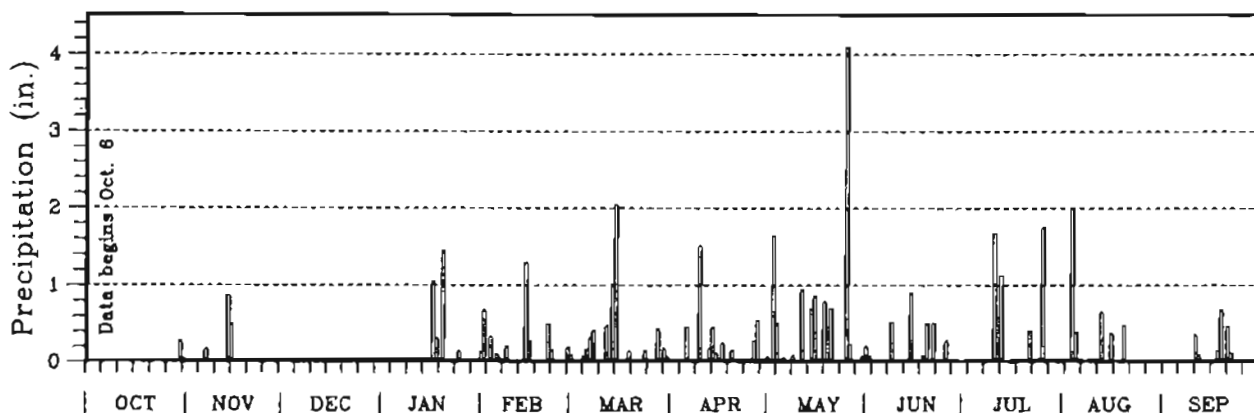


Table 7 and Figure 10: Daily precipitation, Spring Hollow #1 weather observation station.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE HOLLIS BRANCH WEATHER OBSERVATION STATION

WEBSTER COUNTY, SW1/4 NE1/4 SEC. 33, T. 32 N., R. 18 W.
 37 DEG 27 MIN 00 SEC NORTH LATITUDE, 92 DEG 54 MIN 55 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1180 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: RAY AND BARNEY BRYANT TIME GAGE IS READ: 8:00 AM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED NOV 1, 1989, 1 YEAR OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	0.24	....	....	0.15	....	....	....	....
2	****	0.70	....	....	....	....	....	....	....
3	****	1.95	....	....	....	....
4	****	0.44	0.40	....	....	0.60	....	....	1.25	....
5	****	0.90	....
6	****	0.12	0.16	....	....	....	....	....	....
7	****	0.70	....	....	....	....	....	....
8	****	0.40	....	0.40	....	....	....	....	....	....	0.20
9	****	0.82	....	....	....
10	****	1.35	....	....	....	....	0.40
11	****	1.00	....	....
12	****	0.58	....	0.94	....	0.03	....	....
13	****	0.44	....	....	0.93	0.22	0.60
14	****	1.00	....	....	....	0.60	....	0.15	....	....	....	....
15	****	0.19	0.30	....	1.85	2.25	0.07	1.00	0.46	0.15	....	....
16	****	0.15	....	....	0.98	....	....	1.05	....
17	****	0.10	1.65	....	....	0.94	0.20	....	....	0.98	....
18	****	0.62	....	....	0.19	....	....	....	....	....
19	****	0.48	0.44	....	....	0.90
20	****	1.95	....	....	....	....	0.90	....	0.52	....
21	****	1.10	....	0.20	....	1.10
22	****	0.19	....	....	0.60	....	....	....	1.10	....	....	....
23	****
24	****	0.25	....	....	....	....	....	....
25	****	0.10	....	....	....	....	....	....	....	....
26	****	0.05	....	....	1.50	....	1.50	....	....
27	****	0.42	0.60	....	....	....	....
28	****	0.22	1.50	0.44	....	....	....	....	....
29	****	0.28	....	....	....	....	....	....	....	....	....
30	****	0.17	....	....	....	....	....	0.20
31	****	0.38	....	....	....	....
MONTHLY TOTALS	****	1.38	1.08	4.76	4.73	6.21	3.85	10.03	3.72	3.81	4.92	3.40
TOTAL PRECIPITATION: 47.89 INCHES (NOV-SEP)												
NUMBER OF DAYS WITH PRECIPITATION: 73												

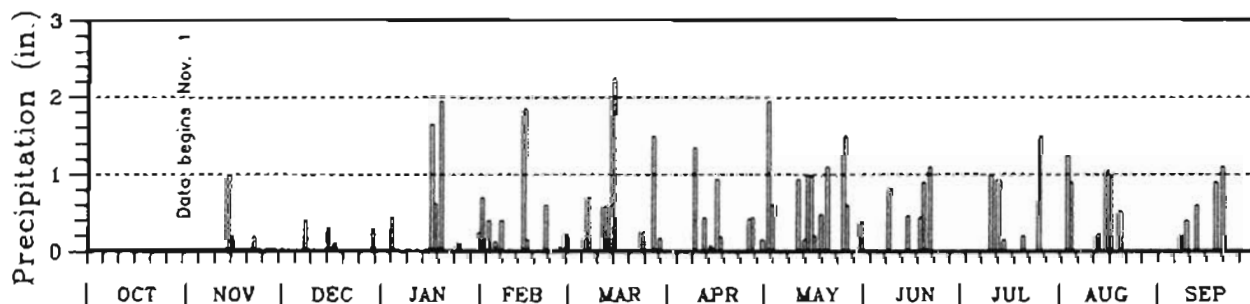


Table 8 and Figure 11: Daily precipitation, Hollis Branch weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE SPRING HOLLOW #2 WEATHER OBSERVATION STATION

LACLEDE COUNTY, SW1/4 NE1/4 SEC. 35, T. 34 N., R. 17 W.

37 DEG 37 MIN 26 SEC NORTH LATITUDE, 92 DEG 46 MIN 08 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 1295 FEET ABOVE MEAN SEA LEVEL

WEATHER OBSERVER: JAMES E. VANDIKE

TIME GAGE IS READ: CONTINUOUS RECORDER

INSTALLATION OPERATED BY: DNR-DGLS

TYPE OF INSTALLATION: TIPPING BUCKET RAIN GAGE AND 31 DAY EVENT RECORDER

STATION INSTALLED NOVEMBER 6, 1989, 1 YEAR OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	****	0.80	0.27	....	0.12	0.07	....	....	....
2	****	****	0.01	....	....	0.57	....	....	....	....
3	****	****	0.44	0.15	....	....	1.79	....	....	1.98	....
4	****	****	0.33	....	....	0.01	....	....	0.50	....
5	****	****	0.01	0.14	0.14	0.35	0.12	....	....	....	....
6	****	0.06	0.23	....	....	....	....	....	....
7	****	0.43	....	....	....	....	....	....
8	****	0.10	....	0.05	0.02	....	....	....	....	....	0.10
9	****	0.16	....	0.20	....	0.65	0.14	0.44	....	....	....
10	****	0.88	....	....	....	....	0.11
11	****	0.54	....	0.56	....	1.45	0.03	0.02
12	****	0.01	0.16	....	2.21	0.17	0.17
13	****	0.55	....	....	0.01	0.54	0.55	....	....	0.03	....	....
14	****	3.89	....	....	0.94	2.05	....	0.16	0.45	....	....	....
15	****	0.73	0.02	0.11	0.50	....	....	0.49	....
16	****	0.73	....	....	0.08	0.51	....	....	0.21	....
17	****	1.04	....	....	0.12	....	....	....	....	0.02
18	****	0.11	....	....	....	....	....	0.90
19	****	1.48	....	....	....	0.65	....	....	0.41	....
20	****	0.05	0.34	0.15	....	....	0.04
21	****	0.15	....	....	0.47	....	0.01	0.52	....	0.73	....	0.51
22	****	0.26	0.06	0.01	....	....	0.02	....	....
23	****	0.02	....	....	....	....	....	....
24	****	0.13	....	0.04	....	0.01	....	....	....	....
25	****	0.23	....	....	0.61	....	0.37	....	0.05	....	....
26	****	0.01	....	0.06	....	3.57	....	2.06	....	....
27	****	0.08	0.13	0.78	0.33	....	....	....	....
28	****	0.05	....	0.11	0.29	....	....	....	....	....	....
29	****	0.24	....	....	....	....	....	....	....	....	....
30	****	0.16	0.01	....	....	....	....	0.05
31	****	0.03	....	....	....	....	....	....
MONTHLY TOTALS	****	4.58	0.78	3.84	4.34	5.75	3.61	10.43	1.11	6.55	3.79	1.92

TOTAL PRECIPITATION: 46.70 INCHES (NOV-SEP)

NUMBER OF DAYS WITH PRECIPITATION: 107

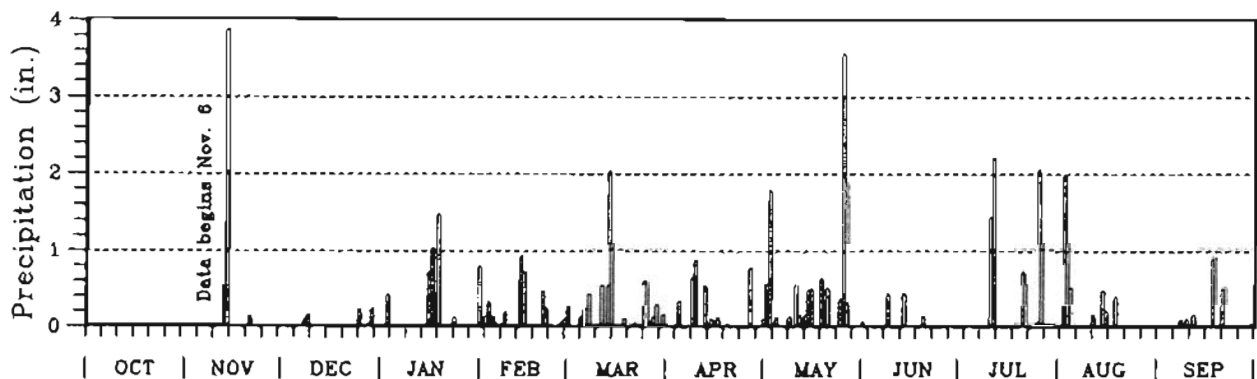


Table 9 and Figure 12: Daily precipitation, Spring Hollow #2 weather observation station.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE PATTERSON BRANCH WEATHER OBSERVATION STATION

DALLAS COUNTY, SE1/4 SW1/4 SEC. 11, T. 32 N., R. 19 W.
 37 DEG 30 MIN 02 SEC NORTH LATITUDE, 92 DEG 59 MIN 34 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1160 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: DEXTER HOLMES TIME GAGE IS READ: AM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED NOV 10, 1989, 1 YEAR OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	****	0.40	0.04	....	****	****
2	****	****	1.95	....	....	1.45	....	....	****	****
3	****	****	****	****
4	****	****	0.60	....	....	****	****
5	****	****	0.45	....	....	....	****	****
6	****	****	1.03	....	....	1.15	....	****	****
7	****	****	0.70	....	....	....	....	....	****	****
8	****	****	****	****
9	****	****	0.30	....	****	****
10	****	****	1.75	....	....	....	****	****
11	****	0.65	....	0.20	....	1.10	****	****
12	****	0.80	....	....	****	****
13	****	0.30	0.50	....	....	....	....	....	....	....	****	****
14	****	0.52	....	....	....	1.30	....	....	0.90	1.20	****	****
15	****	2.05	....	0.80	....	....	****	****
16	****	1.20	1.75	....	1.70	1.00	....	....	****	****
17	****	0.30	0.05	....	....	....	....	....	****	****
18	****	****	****
19	****	0.70	1.75	....	....	0.20	....	....	....	****	****
20	****	0.11	....	....	....	....	....	0.20	....	....	****	****
21	****	1.30	....	0.25	****	****
22	****	0.55	....	....	....	....	....	****	****
23	****	****	****
24	****	0.15	....	1.25	....	....	....	....	****	****
25	****	0.10	....	....	....	....	0.90	....	****	****
26	****	0.45	0.80	****	****
27	****	0.50	2.45	....	....	****	****
28	****	0.45	....	....	....	....	....	****	****
29	****	0.55	....	....	....	....	****	****
30	****	0.80	....	....	....	....	....	....	....	****	****
31	****	0.20	....	....	****	****
MONTHLY TOTALS	****	0.93	2.00	3.50	5.45	6.83	4.60	9.40	3.74	3.35	****	****
TOTAL PRECIPITATION: 39.80 INCHES (NOV-JUL)												
NUMBER OF DAYS WITH PRECIPITATION: 49												

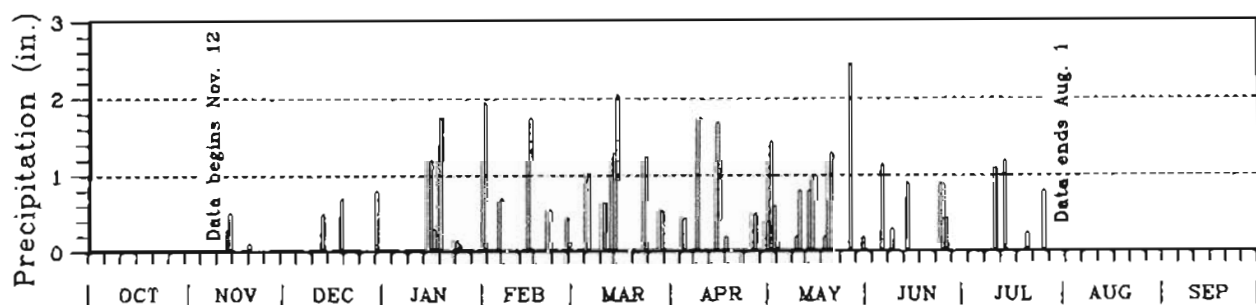


Table 10 and Figure 13: Daily precipitation, Patterson Branch weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE LOUISBURG WEATHER OBSERVATION STATION

DALLAS COUNTY, NE1/4 SE1/4 SEC. 15, T. 35 N., R. 20 W.
 37 DEG 46 MIN 36 SEC NORTH LATITUDE, 93 DEG 07 MIN 01 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1170 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: DENNIS AND SUE JOHNSON TIME GAGE IS READ: 10:00 AM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED DEC 11, 1989, 1 YEAR OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	****	****	0.21	....	....	....	....	....	0.04	....
2	****	****	****	0.49	....	....	....	0.22	....	....	....
3	****	****	****	0.17	....	....	1.24	....	....	1.27	....
4	****	****	****	0.60	0.23	....	....	1.26	....	....	....	....
5	****	****	****	****
6	****	****	****	0.15	0.20	....	....	....	0.92	....	....
7	****	****	****	****	0.41	....	....	....	....	....	0.13
8	****	****	****	****	0.28	....	....	....	....	....	....
9	****	****	****	0.28	....	....	....	0.72	....	....	....
10	****	****	****	****	1.00	....	....	....	....	....
11	****	****	1.30	....	0.44
12	****	****	0.71	....	....	....	0.70	0.13	....
13	****	****	0.18	....	....	1.27	....	....
14	****	****	1.60	1.02	1.73	2.15	....	....	....
15	****	****	1.45	1.75	0.05	0.37	....	....	....	....
16	****	****	0.12	....	....	1.14	....	....	....	....
17	****	****	0.64	....	....	....	0.30	....	....	....	0.32
18	****	****	0.03	....	....	....	0.28	....	....	....	1.24
19	****	****	0.06	....	0.42	0.03	....	0.72	....	....	....
20	****	****	1.70	....	....	0.27	....	0.72	....	....	....
21	****	****	0.93	....	....	....	0.52
22	****	****	0.65	....	....	....	....	0.50	....	0.34
23	****	****	0.42	....	0.05	....	....	....	....	....
24	****	****	0.10	....	....
25	****	****	1.13	0.40	....	....
26	****	****	0.06	....	....	0.78	0.34	....	....	....
27	****	****	0.18	....	0.15	0.91	....	....	....	....
28	****	****	0.37	....	....	....	....	....
29	****	****	0.42	....	....	0.83	....	....	....	....	....	....
30	****	****	0.01	....	....	0.09	....	0.23	....	....	....	....
31	****	****
MONTHLY TOTALS	****	****	0.43	3.03	4.41	6.29	3.12	9.17	6.00	5.19	1.44	2.99

TOTAL PRECIPITATION: 42.07 INCHES (DEC-SEP)

NUMBER OF DAYS WITH PRECIPITATION: 71

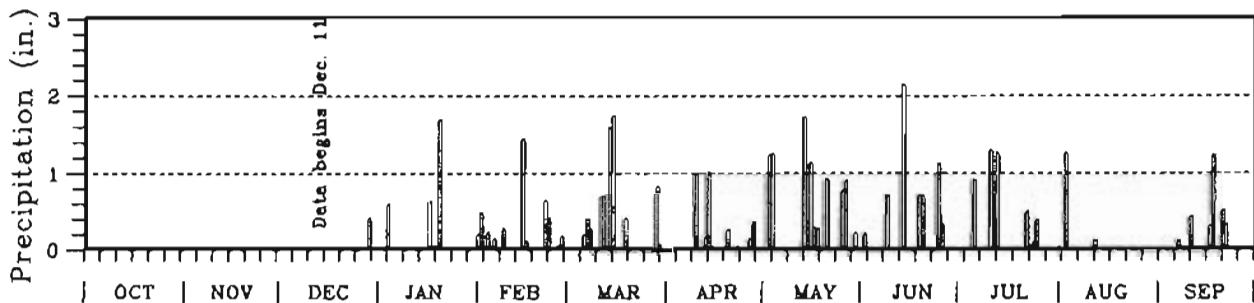


Table 11 and Figure 14: Daily precipitation, Louisburg weather observation station.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE JONES CREEK WEATHER OBSERVATION STATION

DALLAS COUNTY, SE1/4 SE1/4 SEC. 3, T. 32 N., R. 18 W.
 37 DEG 30 MIN 57 SEC NORTH LATITUDE, 92 DEG 53 MIN 31 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1212 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: ROY KNIGHT TIME GAGE IS READ: 8:00 AM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED JAN 1, 1990, 0 YEARS OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	****	****	0.90	0.24	....	0.14	0.22	....	....	....
2	****	****	****
3	****	****	****	0.46	0.16	....	....	1.75	....	....	1.50	....
4	****	****	****	1.52	....	....	0.56	....
5	****	****	****	0.20	0.60	....	....	....	....	....
6	****	****	****	0.12	....	....	0.06	....	....	....	....
7	****	****	****	0.94	....	....	....	....	....	0.10
8	****	****	****	0.14	....	....	....	....	....	....
9	****	****	****	0.40	....	....	0.09	0.62	....	....	....
10	****	****	****	1.65	....	....	....	....	0.70
11	****	****	****	0.66	....	....	....	1.44	....	....
12	****	****	****	0.90	....	1.14	....	....	0.80	0.32
13	****	****	****	2.00	0.50	....	....	0.45	....	....
14	****	****	****	0.06	0.38	0.25	....	....
15	****	****	****	1.70	....	0.10	0.70	....	....	0.70	....
16	****	****	****	0.36	....	....	0.50	1.24	....	....	0.10	....
17	****	****	****	1.87	....	....	0.86	....	....	....	....	0.07
18	****	****	****	0.20	....	....	....	1.05
19	****	****	****	1.75	....	0.13	....	0.50	0.46	....	0.45	....
20	****	****	****	0.18	....	1.00	....	....	0.13
21	****	****	****	0.17	2.30	....	0.22	....	0.82
22	****	****	****	0.50	....	....	....	0.80	0.84	....	....
23	****	****	****	0.02	0.18	1.36	....	....	....	....	....	....
24	****	****	****
25	****	****	****	0.20	0.17	....	....
26	****	****	****	0.01	1.63	0.22	2.08	....	....
27	****	****	****	0.14	....	1.16	0.82	....	....	....	....
28	****	****	****	0.16	0.52	....	....	....	....	....	....
29	****	****	****	0.12	....	....	....	0.18
30	****	****	****	0.75	0.08	....	....	....	....	....
31	****	****	****	0.08	....	....	....	....
MONTHLY TOTALS	****	****	****	4.46	4.26	7.84	5.81	12.35	3.90	5.45	4.11	3.37

TOTAL PRECIPITATION: 51.55 INCHES (JAN-SEP)

NUMBER OF DAYS WITH PRECIPITATION: 81

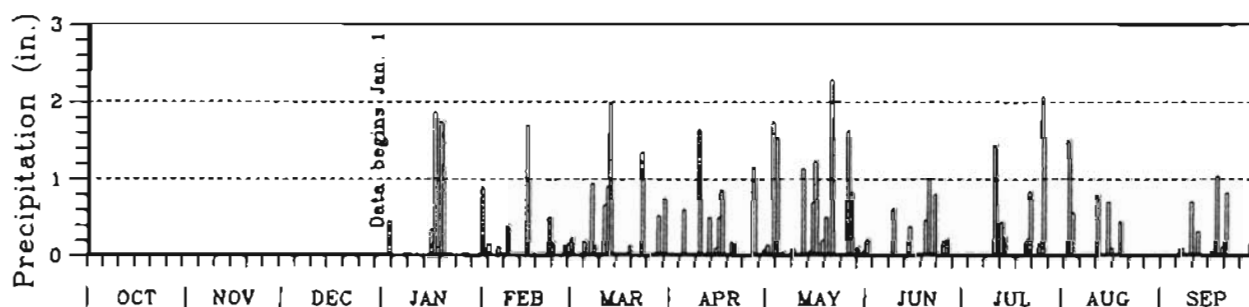


Table 12 and Figure 15: Daily precipitation, Jones Creek weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE STEINS CREEK NEAR ORLA WEATHER OBSERVATION STATION

LACLEDE COUNTY, SE1/4 NE1/4 SEC. 2, T. 32 N., R. 15 W.

37 DEG 30 MIN 53 SEC NORTH LATITUDE, 92 DEG 32 MIN 55 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 1165 FEET ABOVE MEAN SEA LEVEL

WEATHER OBSERVER: RALPH MASSEY

TIME GAGE IS READ: 6:00 PM

INSTALLATION OPERATED BY: DNR-DGLS

TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE

STATION INSTALLED JAN 11, 1990, 0 YEARS OF DATA

NOTE: *** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	***	***	***	***	0.82	...	...	0.02	0.14	...	...	...
2	***	***	***	***
3	***	***	***	***	0.22	...	...	1.95	...	...	...	...
4	***	***	***	***	0.36	...	...	1.20	...
5	***	***	***	***	...	0.24	0.26	...	...	...	...	...
6	***	***	***	***	0.07	...	...	...	...	0.48	...	...
7	***	***	***	***	...	0.56	...	...	...	...	...	...
8	***	***	***	***	...	0.06	...	...	...	...	...	0.28
9	***	***	***	***	0.50	...	...	...	0.80	...	...	...
10	***	***	***	***	1.26	...	...	...	...	...
11	***	***	***	0.56	...	...	...	1.05	0.05	0.90
12	***	***	***	0.40	0.90	...	...	0.45	0.10
13	***	***	***	0.58	...	...
14	***	***	***	0.50	0.09	0.03	0.48	...	...	...
15	***	***	***	0.20	1.90	0.86	...	0.66	...	...	0.60	...
16	***	***	***	1.50	...	...	0.26	0.62	...	...	0.42	...
17	***	***	***	0.70	...	...	...	...
18	***	***	***	0.11	...	...	...	...	...	1.15
19	***	***	***	1.76	...	...	...	0.62	0.05	0.24	...	...
20	***	***	***	0.12	...	...	...	0.02	0.65	...	...	...
21	***	***	***	...	0.58	...	...	1.00	...	0.22	...	0.94
22	***	***	***	...	0.03	0.06	0.02	...	0.70	0.02	...	...
23	***	***	***	0.70	...	...	...
24	***	***	***	1.00	...	...	...	...	...	...
25	***	***	***	0.04	...	...	...	...	...	...	...	...
26	***	***	***	2.25	...	1.15	...	...
27	***	***	***	...	0.06	0.42	0.22	0.56	...	...	...	...
28	***	***	***	...	0.46	...	...	...	...	...	...	...
29	***	***	***
30	***	***	***	0.48	0.19	...	...	...	...	0.22
31	***	***	***	0.08	...	...	...	...
MONTHLY TOTALS	***	***	***	3.62	4.64	4.85	2.70	9.77	3.52	3.74	2.72	3.59

TOTAL PRECIPITATION: 39.15 INCHES (JAN-SEP)

NUMBER OF DAYS WITH PRECIPITATION: 72

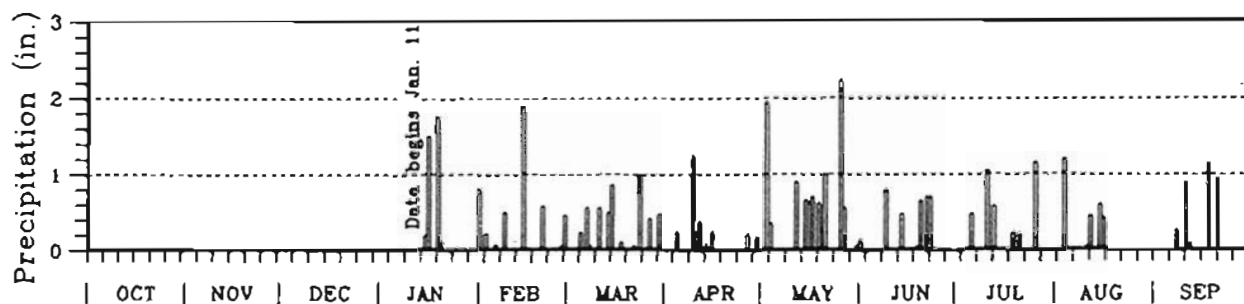


Table 13 and Figure 16: Daily precipitation, Steins Creek near Orla weather observation station.

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE NORTH COBB CREEK WEATHER OBSERVATION STATION

LACLEDE COUNTY, NW1/4 NW1/4 SEC. 33, T. 34 N., R. 15 W.
 37 DEG 37 MIN 18 SEC NORTH LATITUDE, 92 DEG 34 MIN 54 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1222 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: BILL DeVASURE TIME GAGE IS READ: 6:00 PM
 INSTALLATION OPERATED BY: DNR-OGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED FEB 26, 1990, 0 YEARS OF DATA

NOTE: *** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	***	***	***	***	***	...	0.05	0.14	...	...	...	...
2	***	***	***	***	***
3	***	***	***	***	***	2.24	...	...	1.60	...
4	***	***	***	***	***	0.41	...	...	...	0.02
5	***	***	***	***	***	0.08	0.34	0.04	...	0.60	...	...
6	***	***	***	***	***	0.08	...	...	0.47	0.40	...	...
7	***	***	***	***	***	0.70	...	...	...	...	...	...
8	***	***	***	***	***	0.10	...	...	...	...	...	...
9	***	***	***	***	***
10	***	***	***	***	***	0.64	1.26	...	...	...	...	...
11	***	***	***	***	***	1.18	...	...
12	***	***	***	***	***	1.55	...	0.49	0.54	0.80
13	***	***	***	***	***	...	0.48	...	...	0.68	...	...
14	***	***	***	***	***	1.49	0.12	...	...	...	...	0.47
15	***	***	***	***	***	0.48	...	...	...	...	...	...
16	***	***	***	***	***	1.75	...	...	0.58	...
17	***	***	***	***	***	...	0.28	...	...	...	...	...
18	***	***	***	***	***	0.14	...	...	...	...	...	0.70
19	***	***	***	***	***	0.32	...	...	...	...
20	***	***	***	***	***	...	0.28	...	...	...	...	...
21	***	***	***	***	***	...	0.05	0.80	...	0.78	...	0.60
22	***	***	***	***	***
23	***	***	***	***	***	0.45	...	...	...
24	***	***	***	***	***	0.74	...	0.03	...	...	...	...
25	***	***	***	***	***	0.58	...	...	...
26	***	***	***	***	5.50	...	1.48	...	...
27	***	***	***	***	1.25	...	...	...	...	...
28	***	***	***	***	...	0.50	...	0.24	...	...	...	...
29	***	***	***	***
30	***	***	***	***	...	0.39	...	...	...	...	...	...
31	***	***	***	***	0.26	...	...	...	...
MONTHLY TOTALS	***	***	***	***	0.00	5.34	4.11	13.28	1.50	5.60	2.72	2.59

TOTAL PRECIPITATION: 35.14 INCHES (MAR-SEP)

NUMBER OF DAYS WITH PRECIPITATION: 50

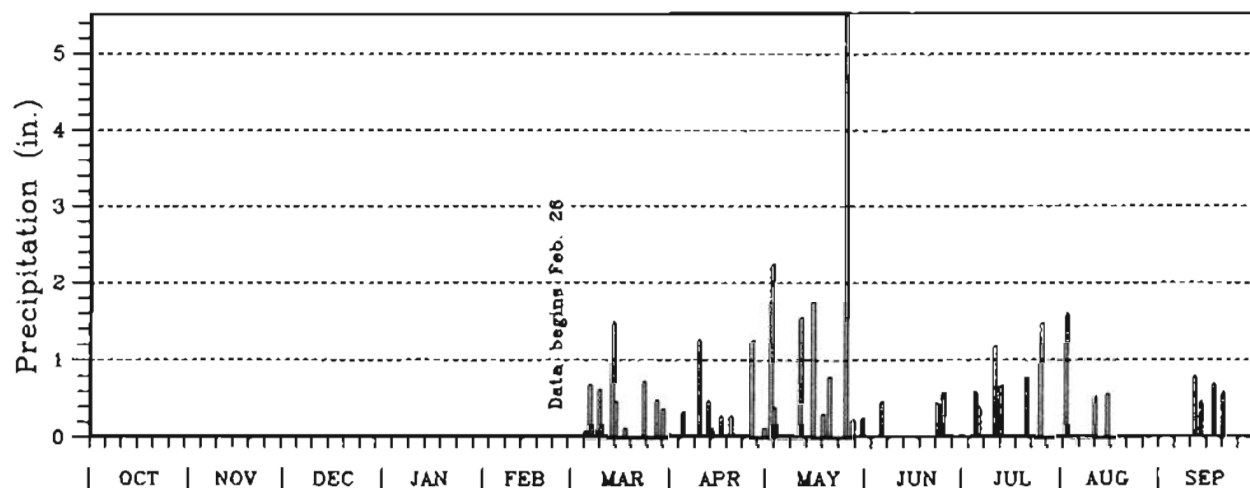


Table 14 and Figure 17: Daily precipitation, North Cobb Creek weather observation station.

The Hydrogeology of the Bennett Spring Area

ANNUAL SUMMARY, WATER YEAR 1989 - 1990, FOR THE LONG LANE WEATHER OBSERVATION STATION

DALLAS COUNTY, NW1/4 NE1/4 SEC. 33, T. 34 N., R. 18 W.
 37 DEG 37 MIN 46 SEC NORTH LATITUDE, 92 DEG 54 MIN 32 SEC WEST LONGITUDE
 LAND SURFACE ELEVATION: 1205 FEET ABOVE MEAN SEA LEVEL
 WEATHER OBSERVER: MICHELLE JONES TIME GAGE IS READ: 8:00 AM
 INSTALLATION OPERATED BY: DNR-DGLS
 TYPE OF INSTALLATION: TRU-CHEK NON-RECORDING RAIN GAGE
 STATION INSTALLED MAR 1, 1990, 0 YEARS OF DATA

NOTE: **** DENOTES MISSING DATA

DAILY PRECIPITATION (INCHES) FOR WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	****	****	****	****	****	0.01	0.06	....	....	....	....
2	****	****	****	****	****	0.07	....	....	....
3	****	****	****	****	****	1.75	....	....	0.60	....
4	****	****	****	****	****	0.71	....	0.10	1.00	....
5	****	****	****	****	****	0.48	0.10	....	....	0.07	....
6	****	****	****	****	****	0.22	....	....	0.03	....
7	****	****	****	****	****	0.28	....	....	....	....	....	0.07
8	****	****	****	****	****	0.62	....	....	....	....	....	....
9	****	****	****	****	****	0.38	....	....	....
10	****	****	****	****	****	1.35	....	....	....	....	....
11	****	****	****	****	****	0.17	....	....	1.40	0.07	....
12	****	****	****	****	****	0.56	....	....	....	0.28	....	0.30
13	****	****	****	****	****	1.76	0.15	0.90	....	0.49	0.22	....
14	****	****	****	****	****	2.17	0.60	....	....	0.05	0.04	....
15	****	****	****	****	****	0.76	0.41	0.10	....	....
16	****	****	****	****	****	0.15	0.70	0.32	....	0.46	....
17	****	****	****	****	****	0.27	0.27	....	....	0.09	1.25
18	****	****	****	****	****	0.12	0.02	....	....	....	....	....
19	****	****	****	****	****	0.60	1.10	....	....	....
20	****	****	****	****	****	0.11	....	....	....	0.70	0.52
21	****	****	****	****	****	0.98	....	....	0.05	0.07
22	****	****	****	****	****	0.05	....	....	....	0.30	....	....
23	****	****	****	****	****	0.50	0.05	....	....
24	****	****	****	****	****
25	****	****	****	****	****	0.03	....	0.28	0.06	....	....
26	****	****	****	****	****	0.56	....	....	0.85	....	....
27	****	****	****	****	****	0.80	....	....	....	0.02	....	....
28	****	****	****	****	****	0.70	0.38	4.25	....	....	....	....
29	****	****	****	****	****	0.07	....	....	....	....	....	....
30	****	****	****	****	****	0.11	0.02	....	....	....	....	....
31	****	****	****	****	****	0.16	....	0.21	....	....	....	....
MONTHLY TOTALS	****	****	****	****	****	7.40	4.30	11.51	3.06	3.70	3.33	2.21

TOTAL PRECIPITATION: 35.51 INCHES (MAR-SEPT)

NUMBER OF DAYS WITH PRECIPITATION: 73

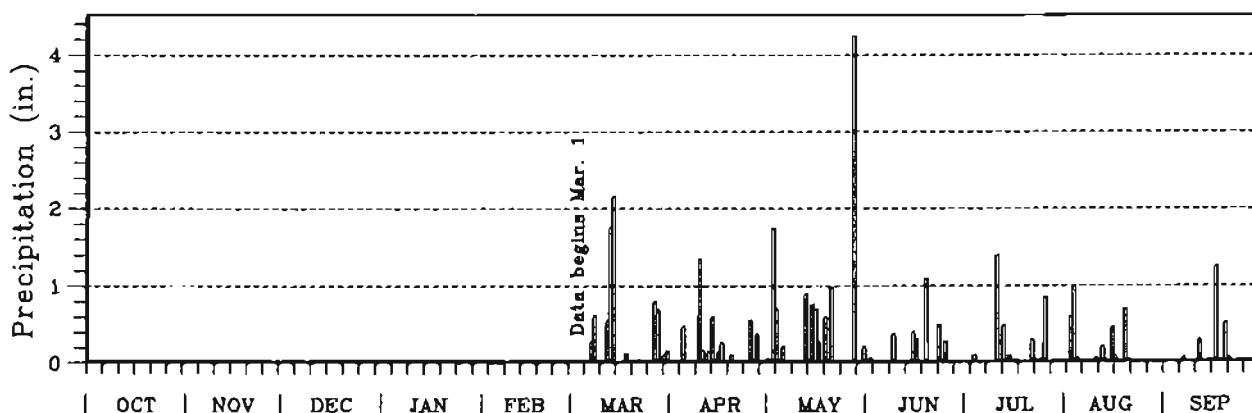


Table 15 and Figure 18: Daily precipitation, Long Lane weather observation station.

Four temporary gaging stations were installed on three losing streams in the study area to study rainfall-runoff relationships in losing-stream watersheds. Compact electrical pressure sensors, called pressure transducers, and digital electronic data recorders called dataloggers, were installed to measure when surface-water runoff occurs, and to estimate the runoff volume. A pressure transducer is a small, pressure sensitive electronic device that can measure water depth (photo 6). Transducers capable of measuring water depths from zero to about 45 feet with an accuracy of about 0.05 feet were installed in 1.2-ft high, 4-inch diameter slotted PVC housings, and anchored in 50 pounds of concrete about 3 feet below grade in the streambeds (photo 7). Transducers were placed below the beds of Fourmile Creek upstream from Route P in Dallas County, in Goodwin Hollow at the Lester Evans farm just northwest of Lebanon, and in Spring Hollow at the King farm. A fourth transducer was installed in the bank of Spring Hollow about 200 feet upstream from Bennett Spring in Bennett Spring State Park (fig. 19).

The pressure transducers were attached by buried cable to dataloggers installed on the valley walls above flood level (photo 8). The cable was placed through 0.625 inch ABS pipe to protect it from abrasion. The dataloggers were installed in 5-foot lengths of 6-inch diameter, 0.188-inch thick steel pipe with the lower 2 to 3 feet of the pipe buried. The transducer cable entered the datalogger housings below ground level, and were attached to the dataloggers (fig. 20).

Dataloggers are small, self-contained, computer-controlled devices that provide power to, and receive and store data from, the pressure transducers. The dataloggers are programmed in the field using a portable computer to enter day, month, and time data, transducer specifications, data-collection interval, and starting time (photo 9). The portable computer is also used to read data from the datalogger. The datalogger-pressure transducer installations were programmed to activate each 60 minutes, measure depth of water in the channel, record the value, then deactivate. Internal memory and battery packs in the dataloggers are capable of recording three months of data taken at 60-minute intervals.

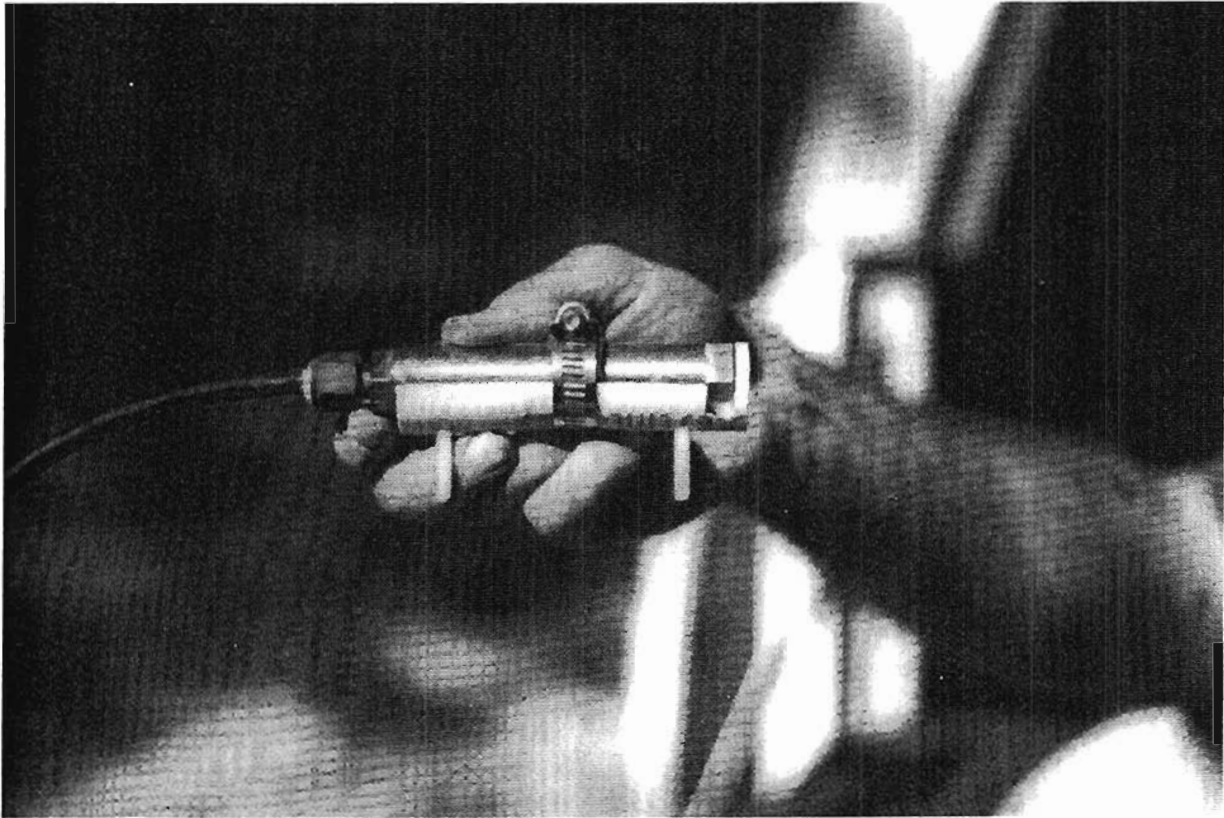
The datalogger-pressure transducer installations measure stream stage or the depth of water in the

channel, not flow rate. Stage-discharge relationships must be established to develop a rating table for the gaging site. To do this, discharge measurements were made at the gaging installations using a current meter when there was flow in the streams, and the discharge was plotted against stage height. Discharges too small to measure were visually estimated. Unfortunately, because of infrequent flows on these losing streams, only a relatively small number of measurements could be made during periods of low and moderate flow. Measurements during high-flow periods when water depth and velocity were too great for wading were not possible. The discharge measurements were generally adequate to develop a reasonably accurate stage-discharge relationship for low and moderate flows, but an indirect method was required to estimate high discharges.

A water-surface profile computer program, HEC-2, developed by the U.S. Army Corps of Engineers Hydraulic Engineering Center, was used to develop high-discharge stage-discharge relationships for several of the pressure transducer-datalogger installations. To do this, several channel cross-sections were surveyed upstream and downstream of the gaging installation cross-section. A HEC-2 option uses cross-section data, distances between cross-sections, channel and over-bank roughness characteristics, and other information to calculate water-surface profiles at selected flow rates. Stage-discharge values calculated using indirect methods are seldom as accurate as those measured. However, they provide a reasonable approximation of flows occurring during high stream stages. Also, high flow rates on these streams do not occur often, and when they do they seldom last more than a few hours. Thus, even significant errors in estimating discharges at high stages will not greatly change yearly runoff estimates.

HEC-2 was not used to calculate high-flow stage-discharge relationships for the installation on Spring Hollow just upstream from Bennett Spring. Here, the Spring Hollow channel is very shallow. Even during dry weather there are shallow pools in Spring Hollow upstream from Bennett Spring, but a short distance farther upstream the channel is irregular, poorly defined, partly choked with trees and brush, and typically dry. Channel conditions such as these make indirect flow estimates using HEC-2 very difficult. Instead, high-stage discharges here were estimated using the

6.



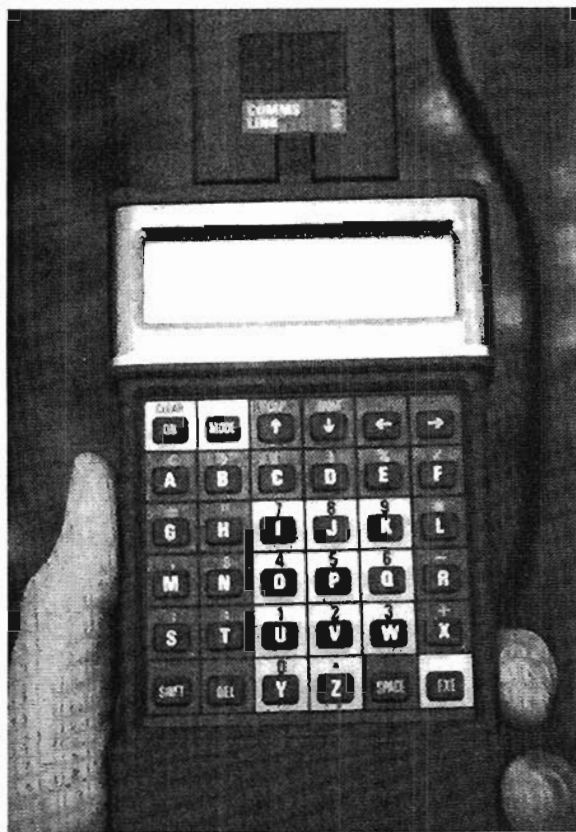
7.



8.



9.



A pressure transducer-datalogger installation consists of a pressure transducer which measures the pressure of water exerted on a membrane in the probe, and a datalogger, which records the pressure at preset intervals. The transducer (**Photo 6.**, upper left) is placed in a protective PVC housing (**Photo 7.**, below left) that is anchored in concrete and buried beneath the streambed. A buried cable connects the pressure transducer with the datalogger (**Photo 8.**, above), which is housed in a steel casing. A hand-held computer (**Photo 9.**, right) is used to program and read data stored in the datalogger.

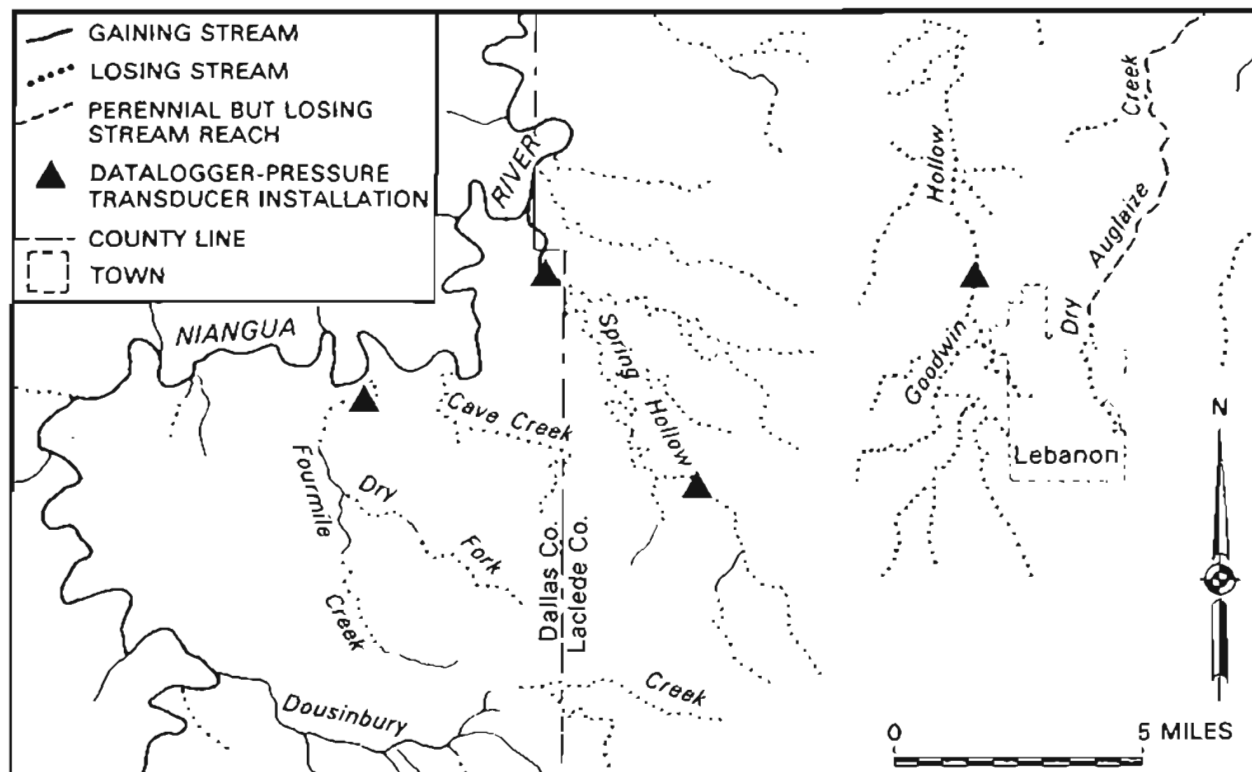


Figure 19: Datalogger-pressure transducer surface-water gaging stations.

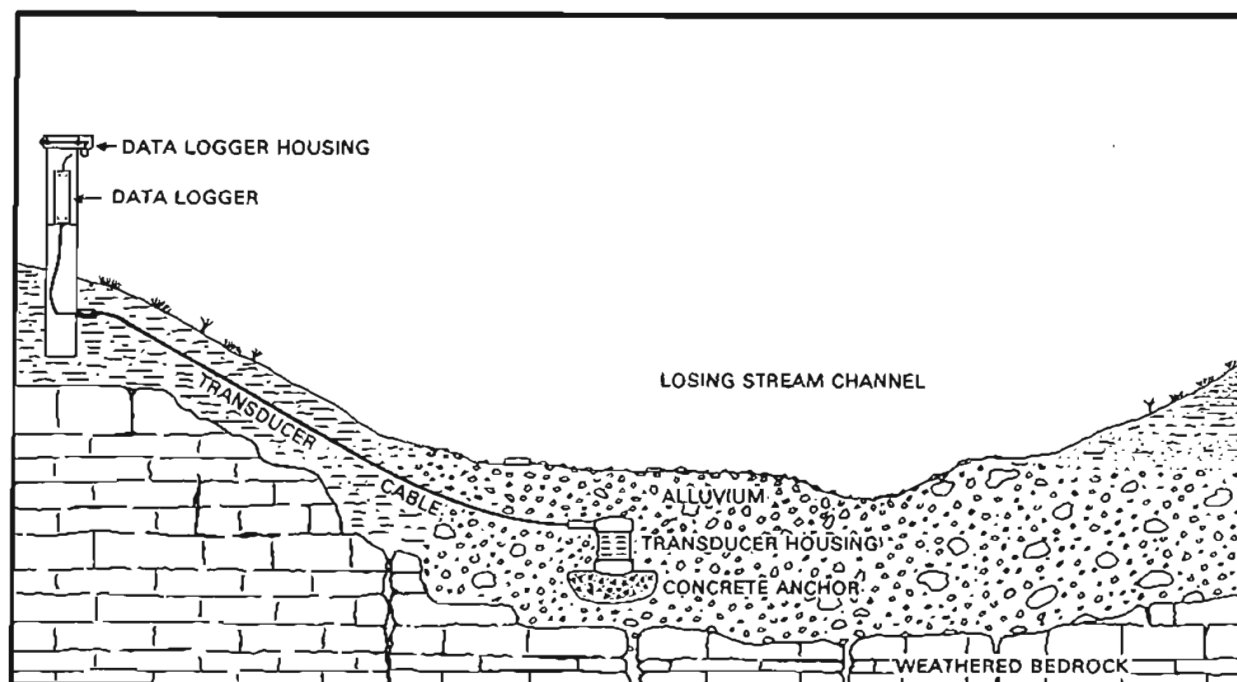


Figure 20: Diagrammatic cross-section showing typical datalogger-pressure transducer gaging station installation.

U.S. Geological Survey rating table for Bennett Spring, which has a maximum stage height of 11.2 feet and a maximum discharge of 14,800 ft³/sec. The Bennett Spring rating table reflects total flow in Spring Hollow below the spring, not just the flow contributed by the spring. It was assumed that Bennett Spring maximum discharge is 1000 ft³/sec, and that flows above this were surface-water runoff from Spring Hollow.

There were several problems with some of the datalogger-pressure transducer installations; some were due to electrical problems with the equipment, others were caused by harsh and unusual environmental conditions. Two data loggers were rendered inoperable from high-voltage surges, probably due to nearby lightning strikes. Transducers at two of the sites were badly damaged when deep scouring of the streambeds during flash-flooding dislodged them and carried them downstream, damaging the electronics in the transducers as well as over-stretching the cables. Unfortunately, time and budgetary constraints did not allow for replacing or immediately repairing the damaged equipment.

Channel characteristics of these losing streams created additional problems. Ideally, a gaging station on a small watershed should be sited upstream of some structure that provides vertical control of stream discharge, such as a low dam, weir, or bedrock outcrop. Gravel-bottomed streambeds change during flow events; zero-flow elevations may increase or decrease, depending on whether gravel is removed or deposited, requiring frequent adjustment of the rating table. Despite these problems, flow data gathered from these streams provides valuable information about the runoff characteristics of major losing streams in the Bennett Spring area.

Both gaging stations installed on Spring Hollow operated continuously through water year 1989-1990. Spring Hollow at the King farm, about 1.5 miles downstream from Highway 32 and 8.3 miles upstream from Bennett Spring, has a drainage area of about 14.95 mi². There is seldom flow in this reach of Spring Hollow; the channel is irregular and floored with coarse gravel, cobbles, and boulders. From October 1, 1989 through September 30, 1990, there were 96 days when flow in Spring Hollow averaged 0.01 ft³/sec (5 gallons per minute) or more. There were 33 days when

average daily flow exceeded 1 ft³/sec (448.8 gpm). For 269 days, including all of October and December, 1989, and September, 1990, there was no flow in Spring Hollow at the King farm (table 16). Approximately 90 percent of the runoff occurred during March, May, and July. May runoff alone accounted for 70 percent of the total due to numerous rainstorms including one where rainfall exceeded 4 inches.

Precipitation during water year 1989-1990, measured at Spring Hollow #1 precipitation station 1,200 feet east of the gaging station and at Spring Hollow #2 precipitation station 2.5 miles to the southeast, averaged 45.5 inches, about 4 inches greater than normal. Total water-year runoff from Spring Hollow watershed above the gaging station was about 2.13 watershed inches, about 12 to 13 watershed inches less than would be expected from a gaining stream with this yearly rainfall amount.

Figure 21 is a hydrograph of Spring Hollow at the King farm showing average daily discharge for the water year. The hydrograph shows runoff generally occurs only briefly in response to heavy precipitation. The major flood which occurred on Spring Hollow in late May, 1990, resulted from nearly 4 inches of precipitation. Data from the recording rain gage station in Spring Hollow showed that 3.90 inches of precipitation fell between 2300 hours on May 25, and about 0400 hours on May 26. Soil in the area was already saturated from about 6.5 inches of rain that had already occurred in May. At 0300 hours, May 26, Spring Hollow was flowing about 1.6 ft³/sec; water depth was a few inches. An hour later water depth in the channel at the gaging station was 7.12 feet, and flow was an estimated 2,450 ft³/sec. Peak recorded flow occurred at 0500 hours at approximately 2,840 ft³/sec with a depth of 7.6 feet. Flow rapidly decreased from 0600 hours with the stage declining as much as 2.2 feet per hour. By 0400 hours May 27, 24 hours after the flood began, discharge had decreased to about 22.4 ft³/sec, and water was less than a foot deep in the channel.

Discharge and runoff characteristics are quite similar for Spring Hollow just upstream from Bennett Spring, with a drainage area of 42.5 mi². Here, during water year 1989-1990, data showed there was 196 days when average daily discharge was 0.01 ft³/sec or more, and 63 days when

The Hydrogeology of the Bennett Spring Area

SUMMARY, WATER YEAR 1989 - 1990, SPRING HOLLOW AT KING FARM GAGING STATION

LACLEDE COUNTY: SE1/4 NE1/4 SEC. 21, T. 34 N., R. 17 W.

37 DEG 39 MIN 08 SEC NORTH LATITUDE, 92 DEG 48 MIN 03 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 1086 FEET ABOVE MEAN SEA LEVEL. MEASURING POINT IS ADJUSTED MINIMUM STREAMBED ELEVATION

DRAINAGE AREA: 14.95 SQUARE MILES, 9568.0 ACRES

TYPE OF INSTALLATION: THOR DATA LOGGER AND PRESSURE TRANSDUCER RECORDER INSTALLED IN 1989, 1 YEARS OF DATA

AVERAGE DAILY DISCHARGE (CUBIC FEET PER SECOND), WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.10	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.04	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.01	25.80	0.04	0.00	4.71	0.00
4	0.00	0.00	0.00	0.00	0.00	0.01	0.01	17.61	0.03	0.00	3.38	0.00
5	0.00	0.00	0.00	0.00	0.00	0.03	0.00	5.10	0.02	0.00	0.02	0.00
6	0.00	0.00	0.00	0.00	0.00	0.02	0.00	4.72	0.01	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.01	0.00	3.58	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.04	0.00	3.21	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.05	0.00	2.99	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.12	13.34	1.78	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.18	4.52	1.18	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.21	1.97	2.40	0.00	69.18	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.25	1.16	0.49	0.00	2.89	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	65.57	1.88	0.83	0.00	0.01	0.00	0.00
15	0.00	11.71	0.00	0.00	0.01	40.40	0.98	2.11	0.00	0.00	0.00	0.00
16	0.00	0.01	0.00	0.00	0.00	5.30	0.37	2.15	0.00	0.00	0.00	0.00
17	0.00	0.01	0.00	0.00	0.00	2.61	0.25	0.00	0.00	0.00	0.00	0.00
18	0.00	0.01	0.00	0.00	0.00	1.14	0.16	0.00	0.00	0.00	0.00	0.00
19	0.00	0.01	0.00	0.00	0.00	0.41	0.12	0.11	0.00	0.00	0.00	0.00
20	0.00	0.01	0.00	0.00	0.00	0.24	0.07	0.02	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.01	0.19	0.05	2.16	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.03	0.13	0.04	0.68	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.01	0.02	0.04	0.03	1.37	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.01	0.01	0.02	0.02	1.69	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.01	0.00	2.28	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	490.77	0.00	21.67	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.64	0.00	0.08	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.98	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	----	0.00	0.00	2.42	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	----	0.00	0.00	0.93	0.00	0.00	0.00	0.00
31	0.00	----	0.00	0.00	----	0.00	----	0.25	----	0.00	0.00	----
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAX	0.00	11.71	0.00	0.01	0.03	65.57	13.34	490.77	0.10	69.18	4.71	0.00
AVG	0.00	0.39	0.00	0.00	0.00	3.77	0.83	19.36	0.01	3.03	0.26	0.00
RUNOFF:												
AC-FT	0	23	0	0	0	232	50	1191	0	186	16	0
INCHES	0.00	0.03	0.00	0.00	0.00	0.29	0.06	1.49	0.00	0.23	0.02	0.00

WATER YEAR EXTREMES: MINIMUM - 0.00 (OCT 1), MAXIMUM - 490.77 (MAY 26), AVERAGE - 2.35

WATER YEAR TOTAL RUNOFF: 1698.4 ACRE-Feet, 2.13 WATERSHED INCHES

Table 16: Average daily discharge, Spring Hollow at King Farm, water year 1989-1990.

average daily discharge was above 1.0 ft³/sec. There were 169 days when there was no measurable flow (table 17).

The May 26, 1990, flood did considerable damage at Bennett Spring. Spring Hollow discharge began increasing at about 0300 hours; increasing from about 4.5 ft³/sec to 28.3 ft³/sec by 0400 hours. At 0500 hours, discharge was about 337 ft³/sec. Major runoff reached Bennett Spring by 0600 hours. Water depth in the pool on Spring Hollow immediately upstream from Bennett Spring increased from 1.7 feet deep at 0300 hours to 7.29 feet deep at 0600 hours, when the flow was about 5,940 ft³/sec. Peak recorded flow occurred an hour later at 0700 hours when it reached an estimated 11,000 ft³/sec. Maximum recorded water depth in the pool above Bennett Spring was 9.60 feet. Overbank flooding along Spring Hollow downstream from Bennett Spring damaged some park property, and removed a section of road at the bridge crossing near the northern end of the park.

Total runoff from Spring Hollow upstream from Bennett Spring was about 2.54 watershed inches in water year 1989-1990, slightly more than measured upstream from the gaging station at the King farm. The volume of runoff was considerably greater because of the larger drainage basin, about 5,760 acre-feet at Bennett Spring versus about 1,700 acre-feet at the King farm. The hydrograph of Spring Hollow upstream from Bennett Spring for water year 1989-1990 is shown in figure 22. Although the discharges are greater than at Spring Hollow at the King farm, the rainfall-runoff responses are quite similar. Duration of flow is greater at the downstream station, but there are instances where flow recorded at the King farm was lost underground, and did not reach the gaging station upstream from Bennett Spring.

Fourmile Creek, a Niangua River tributary upstream from Bennett Spring State Park, drains a 27.5 mi² area in east-central Dallas County. It is a gaining stream in that part of the watershed in the area south and southwest of Long Lane. During dry periods, flow disappears into the subsurface about 3/4 mile upstream from Highway 32, and the stream is typically dry for about the next 2 miles downstream. Here, small springs discharging into Fourmile Creek provide perennial flow for a distance, but about 1.5 to 2 miles upstream from its mouth, flow again disappears into the subsur-

face, and the stream remains dry much of the time in the remainder of its reach.

A pressure transducer and datalogger were installed in the bed of Fourmile Creek about 500 feet upstream from the Route P bridge, approximately 0.6 miles upstream from its confluence with the Niangua River. The stream drains 26.9 mi² upstream from the gaging station. The datalogger operated from October 1, 1989, until May 23, 1990, when it was apparently damaged by lightning. The May 26 flood badly scoured the streambed, dislodging and damaging the transducer.

From October 1, 1989, through January 18, 1990, there was no flow in Fourmile Creek at the gaging station. However, unlike Spring Hollow, there was nearly continuous flow from mid-January through, at least, May (table 18). Occasional observations after May indicate that flow ceased in early August, and the creek remained dry throughout August and September. The hydrograph of the Fourmile Creek (fig. 23) shows it having a better sustained base flow than for Spring Hollow. Runoff is also higher, with 3.81 watershed inches of runoff occurring between October 1, 1989, and May 24, 1990. During the same period, Spring Hollow above Bennett Spring had only 1.12 inches of runoff. Data indicate Fourmile Creek's runoff, in watershed inches, may be three to four times greater than that for Spring Hollow, and total runoff for the water year was likely between 7 and 9 watershed inches.

Goodwin Hollow is one of the most notable losing streams in the Bennett Spring area, as well as in south-central Missouri. It has a drainage area of 72.1 mi², and even in its downstream reaches it remains dry except in very wet weather. A pressure transducer and datalogger were installed in the channel of Goodwin Hollow on the Lester Evans farm just northwest of Lebanon. Upstream from the installation Goodwin Hollow drains 35.7 mi². Although considered a losing stream throughout its reach, there are several locations upstream from Highway 64 where there are nearly perennial pools in Goodwin Hollow. This is likely due to the low permeability of silty and clayey streambed materials allowing water to pond, rather than the water table being at or above stream elevation. Between pool areas, the streambed materials are more coarse and flow occurs only after significant

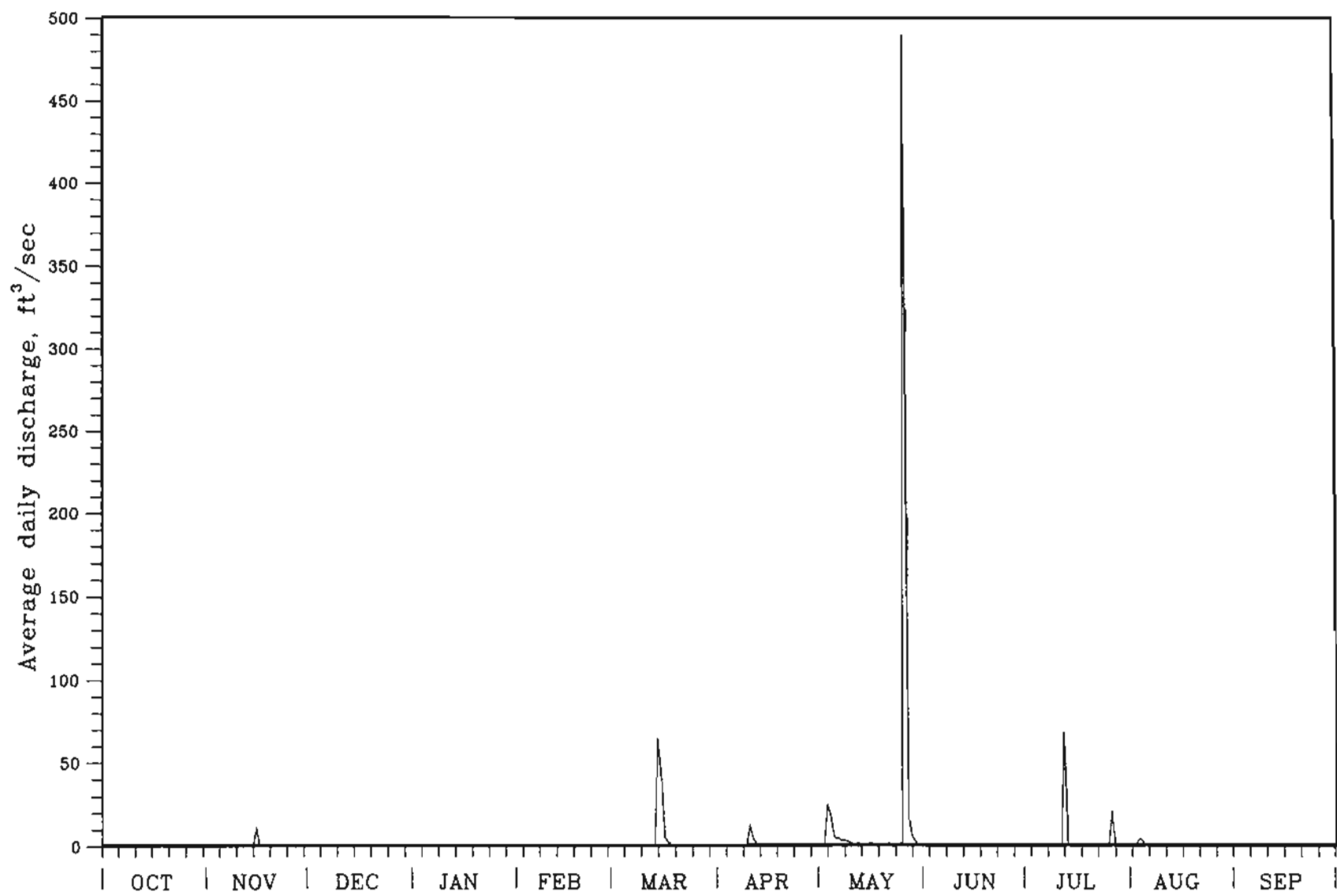


Figure 21: Average daily discharge hydrograph of Spring Hollow at King Farm, water year 1989-1990.

SUMMARY, WATER YEAR 1989 - 1990, SPRING HOLLOW UPSTREAM FROM BENNETT SPRING GAGING STATION

DALLAS COUNTY: NE1/4 NW1/4 SEC. 1, T. 34 N., R. 18 W.

37 DEG 42 MIN 56 SEC NORTH LATITUDE, 92 DEG 51 MIN 23 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 870 FEET ABOVE MEAN SEA LEVEL. MEASURING POINT IS TRANSDUCER BASE

DRAINAGE AREA: 42.5 SQUARE MILES, 27200.0 ACRES

TYPE OF INSTALLATION: THOR 25 PSI PRESSURE TRANSDUCER AND DATA LOGGER RECORDER INSTALLED IN 1989, 1 YEAR OF DATA

AVERAGE DAILY DISCHARGE (CUBIC FEET PER SECOND), WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.00	0.00	0.00	0.00	0.00	0.03	0.95	0.79	2.83	0.01	0.02	0.00
2	0.00	0.00	0.00	0.00	0.00	0.06	0.52	0.45	2.59	0.01	0.02	0.00
3	0.00	0.00	0.00	0.00	0.00	0.15	0.21	99.10	2.03	0.01	0.02	0.00
4	0.00	0.00	0.00	0.00	0.00	0.34	0.09	100.01	1.07	0.01	0.02	0.00
5	0.00	0.00	0.00	0.00	0.00	0.68	0.04	28.20	0.46	0.01	0.02	0.00
6	0.00	0.00	0.00	0.00	0.00	0.87	0.03	8.46	0.25	0.01	0.02	0.00
7	0.00	0.00	0.00	0.00	0.03	0.24	0.02	4.47	0.13	0.01	0.02	0.00
8	0.00	0.00	0.00	0.00	0.04	0.88	0.01	3.08	0.07	0.00	0.02	0.00
9	0.00	0.00	0.00	0.00	0.05	1.12	0.01	2.81	0.05	0.00	0.02	0.00
10	0.00	0.00	0.00	0.00	0.09	0.85	81.44	2.56	0.03	0.00	0.02	0.00
11	0.00	0.00	0.00	0.00	0.07	0.24	27.53	2.18	0.02	0.01	0.02	0.00
12	0.00	0.00	0.00	0.00	0.06	0.26	5.46	2.40	0.02	0.01	0.02	0.00
13	0.00	0.00	0.00	0.00	0.15	2.17	3.14	2.45	0.02	9.60	0.02	0.00
14	0.00	0.00	0.00	0.00	0.08	262.17	6.08	2.11	0.02	0.22	0.02	0.00
15	0.00	0.00	0.00	0.00	0.66	462.14	4.06	2.38	0.02	0.01	0.02	0.00
16	0.00	0.00	0.00	0.00	8.50	13.46	2.34	26.09	0.02	0.02	0.02	0.00
17	0.00	0.00	0.00	0.00	3.25	2.58	1.41	25.87	0.02	0.02	0.02	0.00
18	0.00	0.00	0.00	0.00	1.08	1.28	1.08	7.07	0.02	0.02	0.01	0.00
19	0.00	0.00	0.00	0.00	0.53	0.92	1.17	4.55	0.02	0.02	0.01	0.00
20	0.00	0.00	0.00	0.00	0.29	0.70	1.32	5.96	0.02	0.02	0.01	0.00
21	0.00	0.00	0.00	0.00	0.25	0.47	0.86	18.40	0.02	0.02	0.01	0.00
22	0.00	0.00	0.00	0.00	0.51	0.25	0.66	9.84	0.02	0.01	0.01	0.00
23	0.00	0.00	0.00	0.04	0.45	0.06	0.29	4.28	0.01	0.02	0.00	0.00
24	0.00	0.00	0.00	0.02	0.41	0.05	0.22	2.71	0.01	0.02	0.00	0.00
25	0.00	0.00	0.00	0.00	0.06	0.07	0.25	2.19	0.01	0.02	0.00	0.00
26	0.00	0.00	0.00	0.00	0.02	0.13	0.26	1439.77	0.01	4.41	0.00	0.00
27	0.00	0.00	0.00	0.00	0.02	0.31	0.61	96.59	0.01	1.06	0.00	0.00
28	0.00	0.00	0.00	0.00	0.02	0.70	2.34	33.26	0.01	0.01	0.00	0.00
29	0.00	0.00	0.00	0.00	----	1.75	2.40	10.54	0.01	0.01	0.00	0.00
30	0.00	0.00	0.00	0.00	----	1.56	1.43	5.16	0.01	0.01	0.00	0.00
31	0.00	----	0.00	0.00	----	1.53	----	3.25	----	0.02	0.00	----
MIN	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.45	0.01	0.00	0.00	0.00
MAX	0.00	0.00	0.00	0.04	8.50	462.14	81.44	1439.77	2.83	9.60	0.02	0.00
AVG	0.00	0.00	0.00	0.00	0.59	24.45	4.87	63.13	0.33	0.50	0.01	0.00

RUNOFF:

AC-FT	0	0	0	0	33	1504	290	3882	19	31	1	0
INCHES	0.00	0.00	0.00	0.00	0.01	0.66	0.13	1.71	0.01	0.01	0.00	0.00

WATER YEAR EXTREMES: MINIMUM - 0.00 (OCT 1), MAXIMUM -1439.77 (MAY 26), AVERAGE - 7.96

WATER YEAR TOTAL RUNOFF: 5759.5 ACRE-FEET, 2.54 WATERSHED INCHES

Table 17: Average daily discharge, Spring Hollow upstream from Bennett Spring, water year 1989-1990.

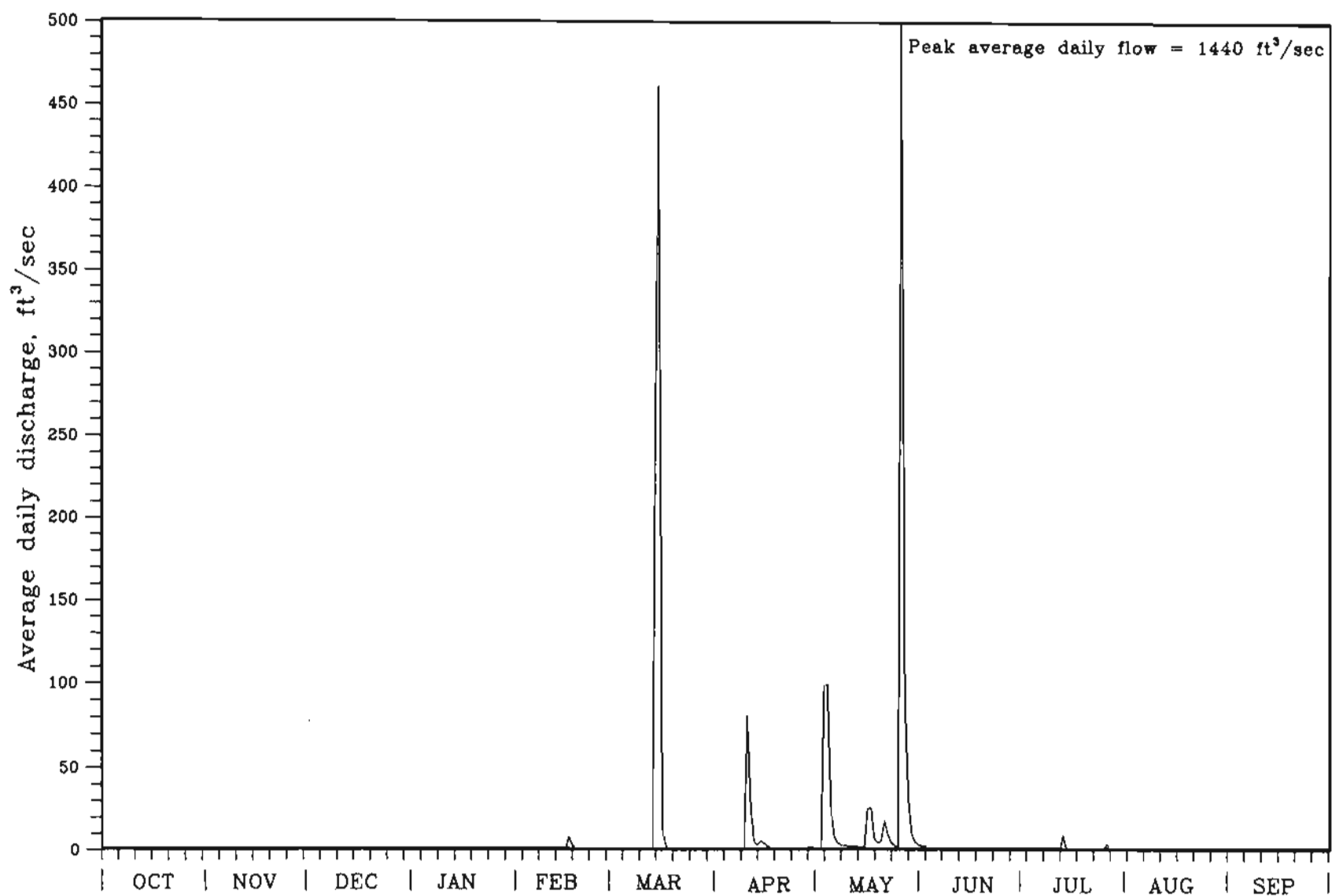


Figure 22: Average daily discharge hydrograph, Spring Hollow upstream from Bennett Spring, water year 1989-1990.

SUMMARY, WATER YEAR 1989 - 1990, FOURMILE CREEK NEAR ROUTE P GAGING STATION

DALLAS COUNTY: SW1/4 SW1/4 SEC. 9, T. 34 N., R. 18 W.

37 DEG 40 MIN 37 SEC NORTH LATITUDE, 92 DEG 55 MIN 13 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 925 FEET ABOVE MEAN SEA LEVEL. MEASURING POINT IS ADJUSTED MINIMUM STREAM BED ELEVATION
DRAINAGE AREA: 26.9 SQUARE MILES, 17216 ACRESTYPE OF INSTALLATION: THOR PRESSURE TRANSDUCER AND DATA LOGGER RECORDER INSTALLED IN 1989, 1 YEAR OF DATA
(NOTE: **** DENOTES MISSING DATA, e-MISSING BUT ESTIMATED)

AVERAGE DAILY DISCHARGE (CUBIC FEET PER SECOND), WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.00	0.00	0.00	0.00	0.00	1.80	16.08	10.13	****	****	****	****
2	0.00	0.00	0.00	0.00	0.26	3.12	14.33	7.60	****	****	****	****
3	0.00	0.00	0.00	0.00	1.31	7.89	10.24	158.44	****	****	****	****
4	0.00	0.00	0.00	0.00	4.53	4.14	16.95	85.18	****	****	****	****
5	0.00	0.00	0.00	0.00	4.34	3.20	11.05	31.80	****	****	****	****
6	0.00	0.00	0.00	0.00	1.39	3.46	13.05	16.53	****	****	****	****
7	0.00	0.00	0.00	0.00	1.48	3.93	25.63	6.37	****	****	****	****
8	0.00	0.00	0.00	0.00	1.47	3.41	19.94	6.11	****	****	****	****
9	0.00	0.00	0.00	0.00	1.83	2.00	11.34	4.14	****	****	****	****
10	0.00	0.00	0.00	0.00	5.32	2.16	136.92	11.16	****	****	****	****
11	0.00	0.00	0.00	0.00	2.24	10.58	52.91	12.81	****	****	****	****
12	0.00	0.00	0.00	0.00	5.05	8.57	32.13	8.00	****	****	****	****
13	0.00	0.00	0.00	0.00	1.72	2.51	13.68	7.21	****	****	****	****
14	0.00	0.00	0.00	0.00	2.51	154.81	28.55	3.70	****	****	****	****
15	0.00	0.00	0.00	0.00	3.69	744.91	26.20	0.58	****	****	****	****
16	0.00	0.00	0.00	0.00	50.73	94.30	9.58	0.59	****	****	****	****
17	0.00	0.00	0.00	0.00	13.90	44.07	12.37	5.59	****	****	****	****
18	0.00	0.00	0.00	0.00	19.82	45.88	11.66e	1.16	****	****	****	****
19	0.00	0.00	0.00	1.39	7.72	32.44	10.94e	0.00	****	****	****	****
20	0.00	0.00	0.00	3.06	5.10	82.22	10.23e	0.00	****	****	****	****
21	0.00	0.00	0.00	2.18	9.60	43.00	9.52e	0.01	****	****	****	****
22	0.00	0.00	0.00	1.76	2.82	9.97	8.80e	0.00	****	****	****	****
23	0.00	0.00	0.00	0.37	1.15	35.44	6.09e	0.08	****	****	****	****
24	0.00	0.00	0.00	1.54	2.92	133.63	7.38	****	****	****	****	****
25	0.00	0.00	0.00	2.14	7.26	60.18	4.88	****	****	****	****	****
26	0.00	0.00	0.00	2.97	8.53	16.94	3.85	****	****	****	****	****
27	0.00	0.00	0.00	0.09	10.79	16.10	3.43	****	****	****	****	****
28	0.00	0.00	0.00	2.94	7.65	12.43	6.60	****	****	****	****	****
29	0.00	0.00	0.00	3.89	----	17.57	3.67	****	****	****	****	****
30	0.00	0.00	0.00	0.04	----	15.96	6.06	****	****	****	****	****
31	0.00	----	0.00	0.00	----	11.56	----	****	----	****	****	----
MIN	0.00	0.00	0.00	0.00	0.00	1.80	0.00	0.00	****	****	****	****
MAX	0.00	0.00	0.00	3.89	50.73	744.91	136.92	158.44	****	****	****	****
AVG	0.00	0.00	0.00	0.72	6.61	52.52	18.20	16.40	****	****	****	****
RUNOFF:												
AC-FT	0	0	0	44	367	3229	1083	748	****	****	****	****
INCHES	0.00	0.00	0.00	0.03	0.26	2.25	0.75	0.52	****	****	****	****

WATER YEAR EXTREMES: MINIMUM - 0.00 (OCT 1), MAXIMUM - 744.91 (MAR 15), AVERAGE - 7.39 (OCT 1-MAY 23)
WATER YEAR TOTAL RUNOFF: 5471.9 ACRE-Feet, 3.81 WATERSHED INCHES (OCT 1-MAY 23)

Table 18: Average daily discharge, Fourmile Creek near Route P, water year 1989-1990.

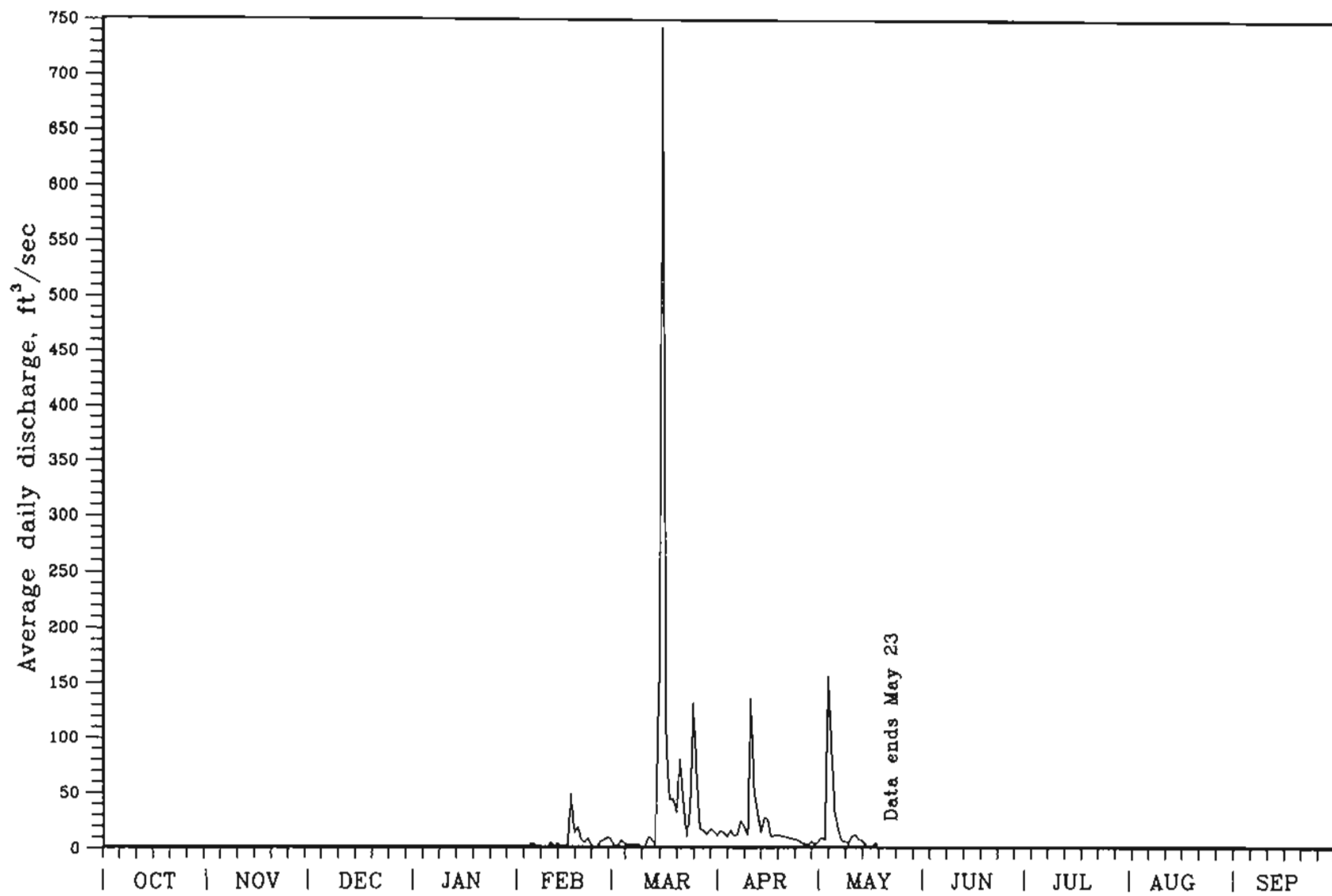


Figure 23: Average daily discharge hydrograph, Fourmile Creek near Route P, water year 1989-1990.

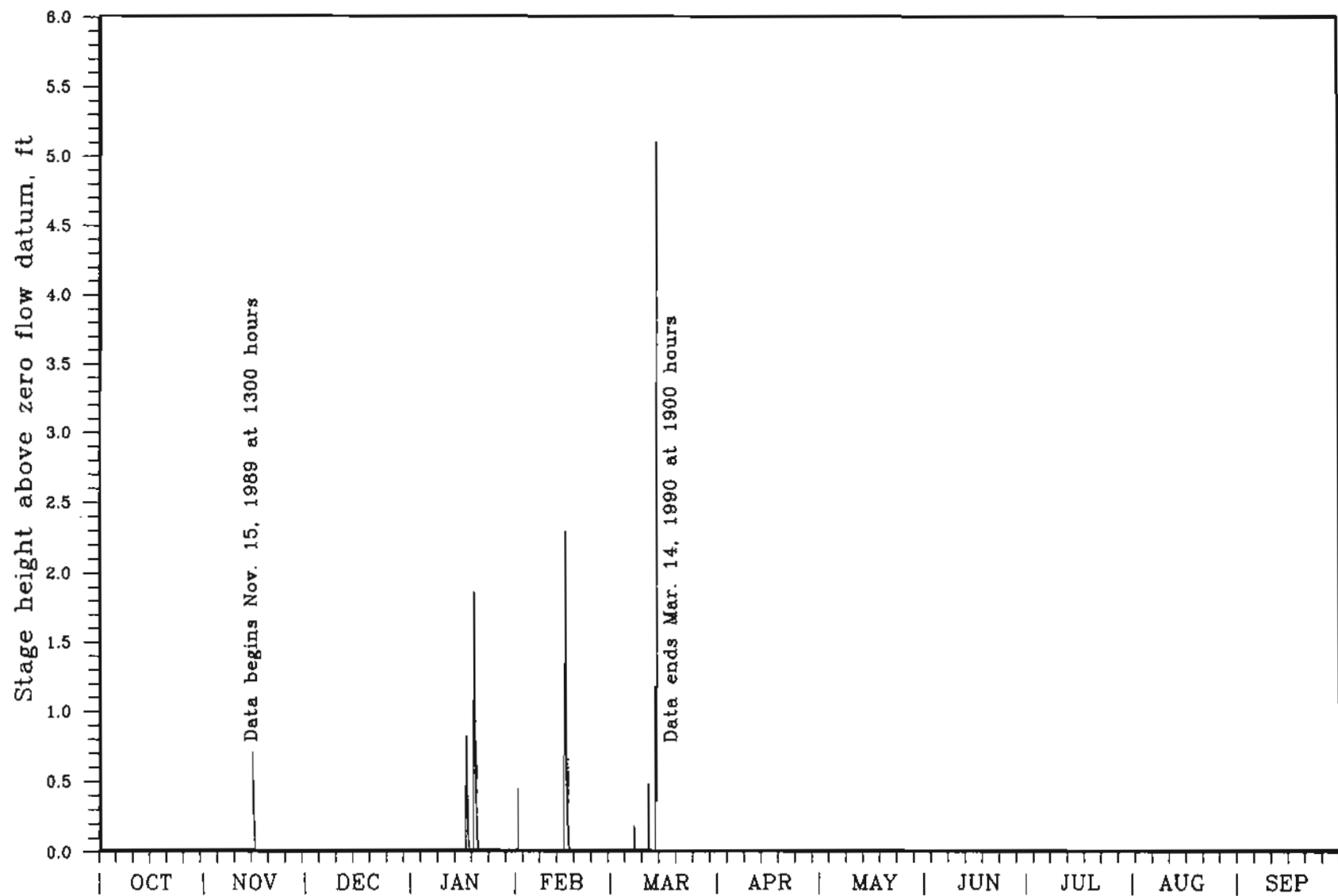


Figure 24: Hourly stage height, Goodwin Hollow at Evans farm, November 15, 1989, through March 14, 1990.



Photo 10. *Goodwin Hollow, a major losing stream in south-central Missouri, drains more than 72 mi², yet is usually dry because it loses most of its flow into the subsurface. Depending on location, water lost into the subsurface in Goodwin Hollow watershed provides recharge to Bennett Spring, Sweet Blue Spring, and Hahalonka Spring.*

rainfall. Between Highway 64 and the gaging station, the channel has a very irregular bed and steep side; bed material consists of gravel in some places but stoney clay and silt in others. Downstream from the gaging station, the channel widens and is floored with gravel, cobbles, and boulders.

There were numerous problems with the Goodwin Hollow gaging station. Equipment malfunction caused data collected between October 2 and November 15, 1989, to be lost. The equipment functioned normally from November 15 until March 13, 1990, when flooding badly scoured the relatively narrow channel, dislodging and damaging the transducer. Data stored in the datalogger was usable, but apparently the datalogger was damaged by lightning and would no longer function properly.

The four-month period of record collected at this site is not sufficient to estimate watershed runoff volume with any accuracy, and no attempt was made to develop a rating table for the station. However, the stage values recorded between November 15, 1989, and March 14, 1990, supplemented with field observations, do provide insight as to the watershed response to precipitation. Figure 24 is a plot of hourly stage heights above the zero flow-point for the period November 15, 1989 to March 14, 1990. There was no significant flow in Goodwin Hollow at the gaging station between October 1, 1989, and November 13, 1989. On November 14 and 15, 1989, Lebanon 2W weather observation station, 1.5 miles south of the gaging station, reported 3.32 inches of rainfall. Data from the gaging station begin 1300 hours November 15 when flow was an estimated 20 to 30 ft³/sec. Flow ended about 1200 hours November 17. Flow occurred again from about 0800 hours January 17, to about 0600 hours January 21, 1990. From January 16 through January 19, Lebanon 2W reported 3.21 inches of rain. At peak flow, the water in Goodwin Hollow at the low-water crossing a few hundred feet downstream from the transducer was about 1.9 feet deep.

Two flow events were recorded in February. The first was minor, and followed about 1 inch of rain. The second, on February 15, after 0.93 inches of rain, resulted in about 2.3 feet of water in the channel. Rainfall in early March caused minor flow to occur in Goodwin Hollow at the gaging station, but the next significant flow event, and the last recorded by the station, was a flood that occurred at 1700 hours March 14, 1990. Relatively small but frequent rainfall events through February and early March did not generate appreciable surface-water runoff in the watershed, but did saturate the soil materials. On March 14 and 15, Lebanon 2W reported 2.75 inches of rainfall, enough to cause flooding in Goodwin Hollow. There was about 8 feet of water in the channel at the transducer (5.1 feet above the zero flow point) when it was scoured from the channel. Although these data do not allow the amount of runoff to be calculated, they do serve to show that Goodwin Hollow upstream of the gaging station loses much of its flow into the subsurface, and responds to heavy precipitation much like Spring Hollow.

MAJOR SPRINGS IN THE BENNETT SPRING AREA

Although this study centers around Bennett Spring and its recharge area, considerable data were also collected from other major springs in the study area. Several of these springs were found to share recharge areas with Bennett Spring, and others have recharge areas that adjoin the Bennett Spring recharge area. Several of these springs are not shown on U.S. Geological Survey 7.5 minute topographic maps, and were previously unreported. No attempt was made to locate all of the springs in the area; there are, undoubtedly, many smaller springs that were not found during the course of this study. Major springs discussed in this report are shown on figure 25. With the exception of Bennett and Hahatonka springs, all of the major springs in the study area are on, or reached by, crossing private property.

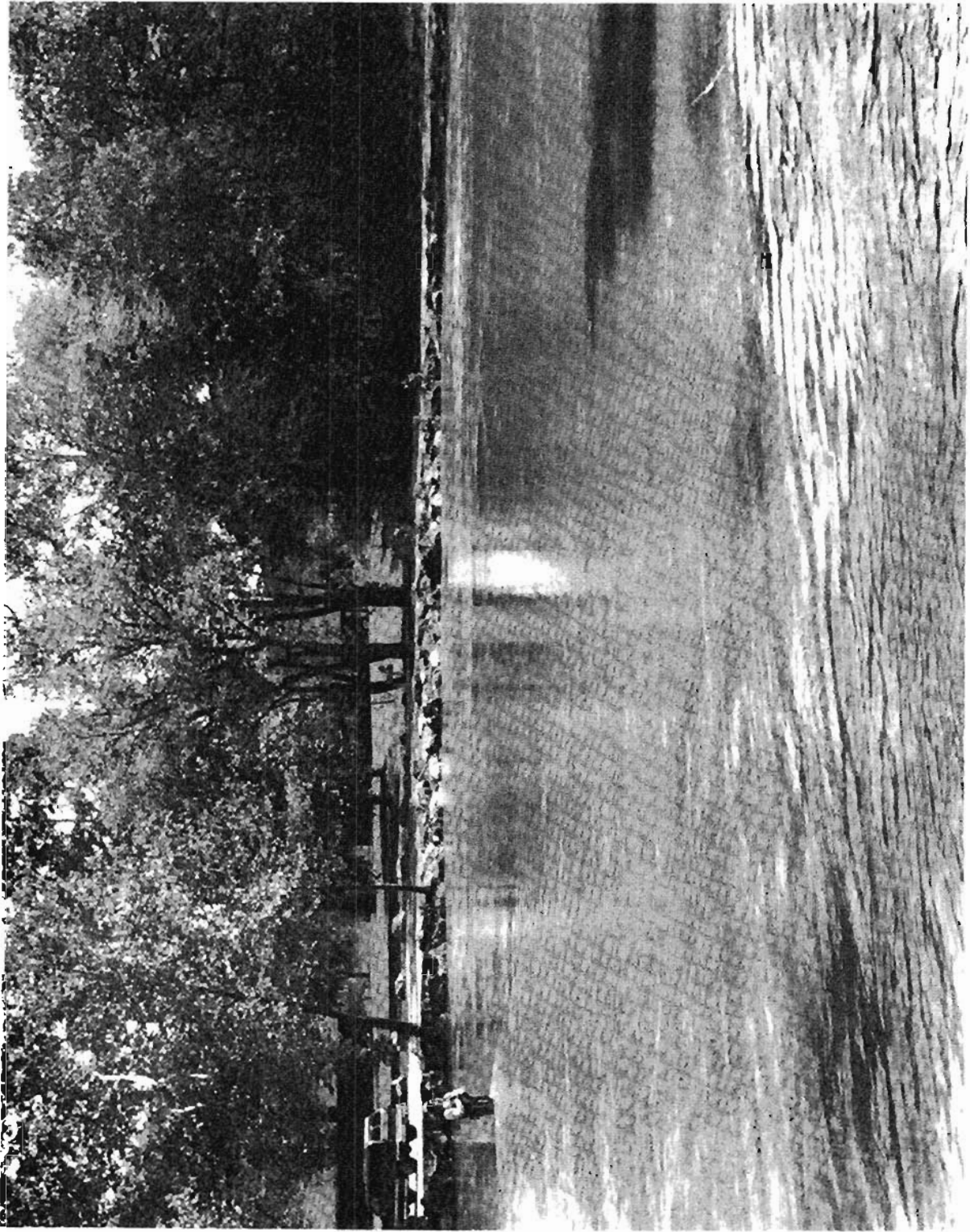


Photo 11. *A lone angler fishes for trout next to the rise pool at Bennett Spring.*

BENNETT SPRING (NW¹/₄ SEC. 1, T. 34 N., R. 18 W.)

Bennett Spring, less than a mile west of the Laclede County line in Dallas County, is the third largest spring in Missouri and the largest spring in the Niangua River basin (photo 11). Water rising from the 50-foot diameter spring basin passes upward through a steeply-inclined phreatic cave passage developed in the Gasconade Dolomite. Divers have explored and mapped the inclined spring conduit to a depth of about 80 feet and a horizontal distance of about 130 feet (fig. 26). The passage continues, but gravel chokes most of it. Higher velocity of the water resulting from the decrease in cross-sectional area has halted exploration (Porter, 1986).

Discharge at Bennett Spring is measured at a stone gage house a few hundred feet downstream of the rise pool. Forty-one years of discharge records are available from the U.S. Geological Survey (1916-1919, 1928-1941, 1965-1990), and the average discharge is 170 ft³/sec, or about 110 million gallons per day. Prior to May 26, 1987, discharges were determined by daily staff gage readings. Since then, stage is measured and recorded every 15 minutes using a digital water-level recorder installed at the gage house. Instead of a single stage observation each day, the recorder takes 96 stage readings in a 24-hour period. Discharges are calculated from stage heights using a rating table developed and maintained by the U.S. Geological Survey.

The Bennett Spring rise pool is in the bottom of Spring Hollow along the east edge of

the channel. There is no spring branch, *per se*, where a gaging station can be constructed to measure only flow from the spring, so reported discharge includes the flow from Bennett Spring plus runoff from Spring Hollow. The pressure transducer-datalogger installation just upstream of the spring allows correction for the surface-water runoff. During water year 1989-1990, average discharge of Spring Hollow at the gaging station downstream of Bennett Spring was 216 ft³/sec (table 19). Average discharge of Spring Hollow upstream from Bennett Spring was about 8 ft³/sec, so the average amount of water discharging from the Spring was actually about 208 ft³/sec (table 20). These data indicate that during a normal year, there is a relatively small difference between discharge measured in Spring Hollow downstream from Bennett Spring, and the actual discharge of the spring. The actual long-term average discharge of Bennett Spring is probably no more than 4 to 5 ft³/sec less than measured at the gaging station, or about 165 ft³/sec.

Figure 27 shows discharge measured at the gaging station downstream from Bennett Spring during water year 1989-1990, which also contains runoff from Spring Hollow. Figure 28, showing discharge of Bennett Spring, was produced by subtracting the average daily flow of Spring Hollow upstream from Bennett Spring from average daily discharge measured just downstream of Bennett Spring.

SAND SPRING (NE¹/₄ SEC. 36, T. 35 N., R. 18 W.)

Sand Spring, also known as Conn Spring, is west of the Niangua River on the south side of Highway 64 a few hundred feet downstream of where Bennett Spring flow enters the river. The spring is in Dallas County about 700 feet from the Laclede County line. The spring rises through the sandy alluvium in the bottom of a shallow mill pond on the Niangua River floodplain; outfall from

the pond flows through a concrete sluice into the spring branch, and into the river (photo 12). The floodplain alluvium overlies Gasconade Dolomite in this area.

Discharge of the spring was measured five times between 1932 and 1964, and averaged 4.85 ft³/sec (Vineyard and Feder, 1974). Minimum and

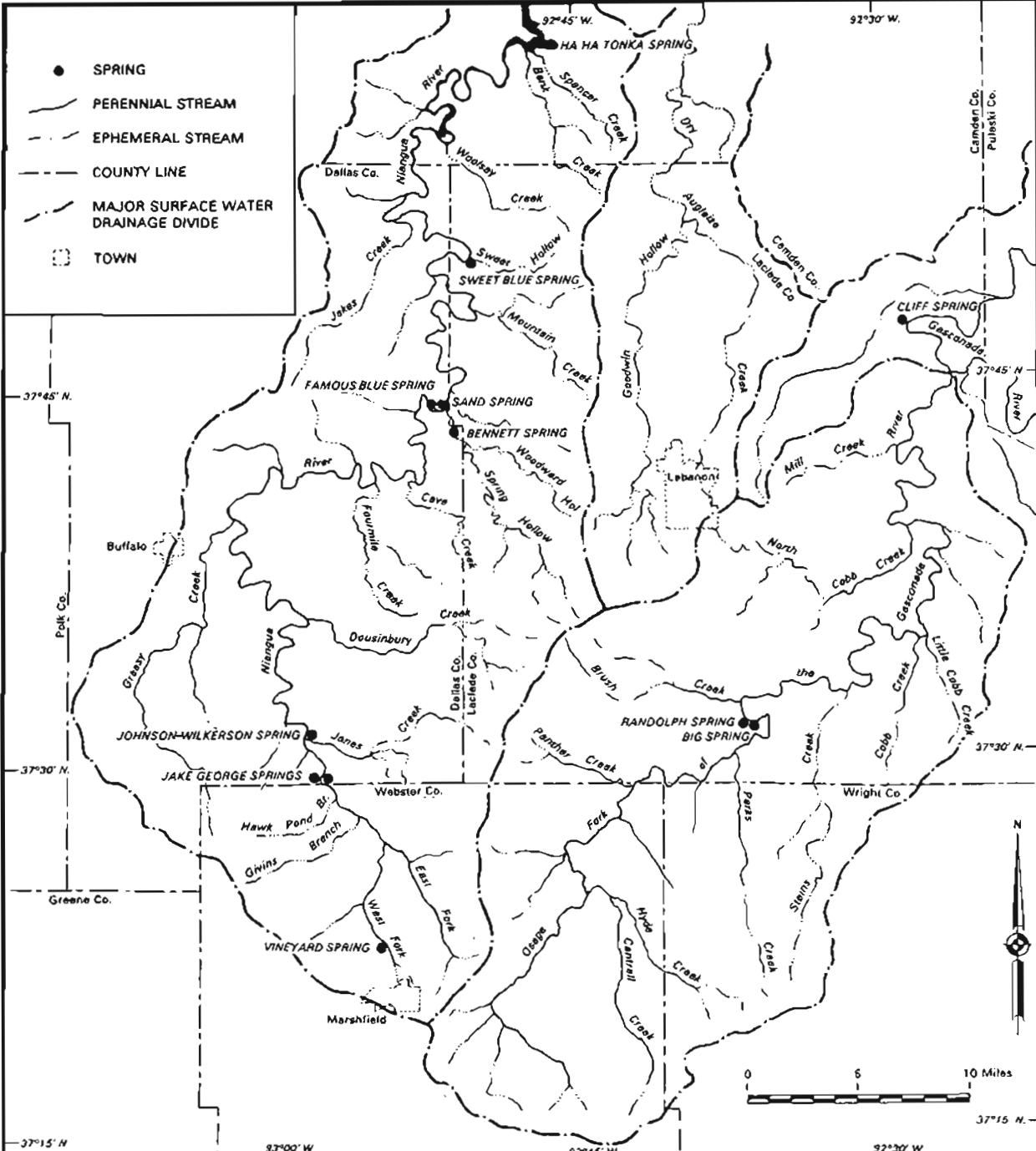


Figure 25: Major springs in the Bennett Spring area discussed in this report.

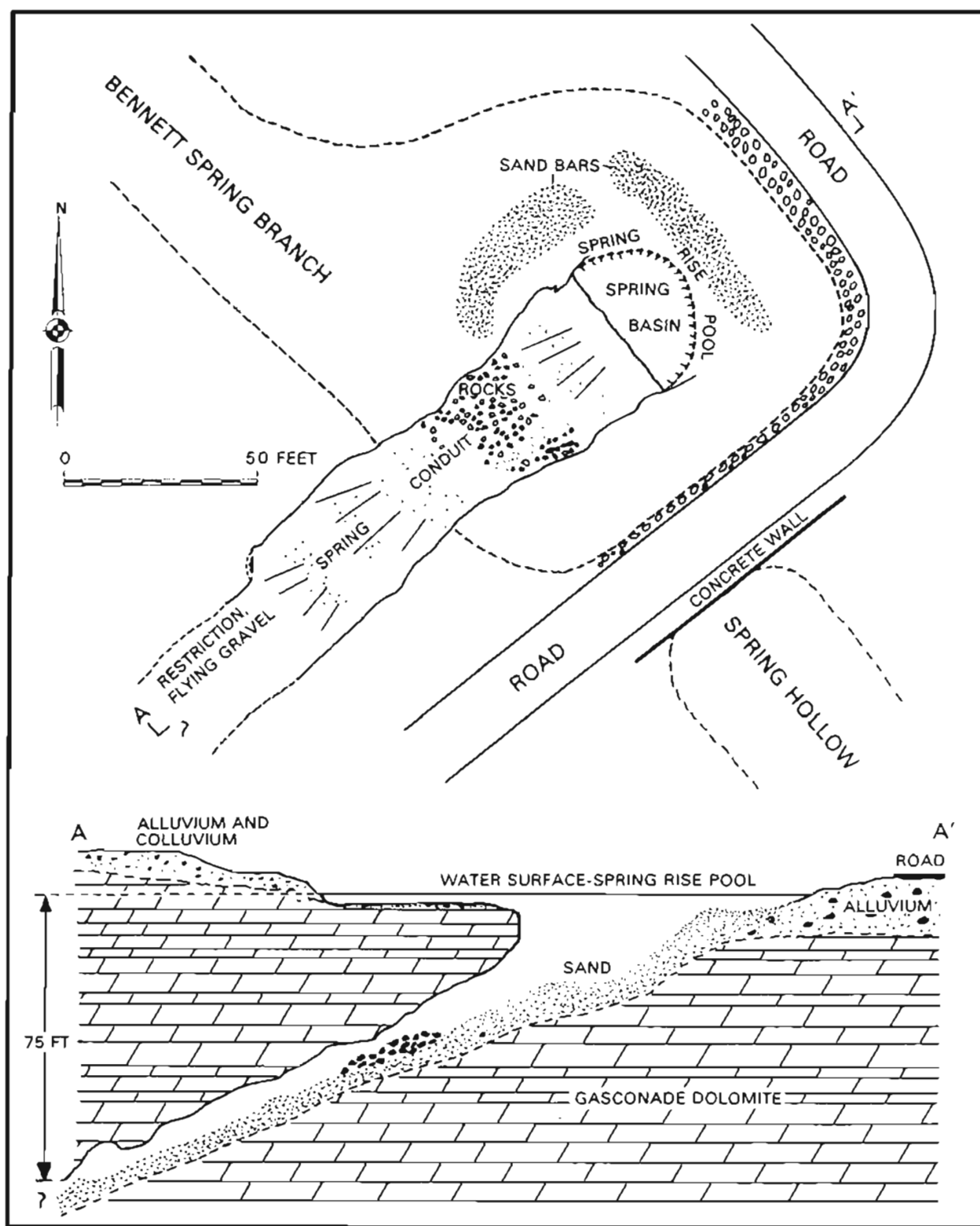


Figure 26: Plan view and cross-section of Bennett Spring. Modified from a map by Porter and Brown, 1984 (in Porter, 1986).

The Hydrogeology of the Bennett Spring Area

SUMMARY, WATER YEAR 1989 - 1990, BENNETT SPRING GAGING STATION (INCLUDES RUNOFF FROM SPRING HOLLOW)

DALLAS COUNTY: NE1/4 NW1/4 SEC. 1, T. 34 N., R. 18 W.

37 DEG 43 MIN 03 SEC NORTH LATITUDE, 92 DEG 51 MIN 26 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 866 FEET ABOVE MEAN SEA LEVEL. MEASURING POINT IS 864.71 FT ABOVE NATIONAL GEODETIC VERTICAL DATUM OF 1929.

SPRING RECHARGE AREA: 265 SQUARE MILES, 169600.0 ACRES. DISCHARGE INCLUDES RUNOFF FROM 42.5 SQUARE MILE AREA IN SPRING HOLLOW WATERSHED.

TYPE OF INSTALLATION: STEVENS DIGITAL WATER STAGE RECORDER INSTALLED MAY 16, 1987. PRIOR TO MAY 16, 1987, NONRECORDING STAGE, 41 YEARS OF RECORD. STATION OPERATED BY THE U. S. GEOLOGICAL SURVEY.

AVERAGE DAILY DISCHARGE (CUBIC FEET PER SECOND), WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	114	105	118	105	132	186	292	252	437	196	183	149
2	114	104	116	105	159	184	281	245	410	194	178	148
3	114	104	116	104	161	184	269	481	382	192	175	148
4	113	104	114	109	161	180	260	607	361	188	237	148
5	114	105	114	108	172	177	252	519	342	185	245	148
6	115	105	112	106	178	174	247	449	328	185	211	148
7	115	108	112	105	182	181	241	402	314	183	196	148
8	114	104	110	105	179	259	234	371	300	181	187	148
9	114	104	110	104	176	272	229	348	292	179	181	148
10	113	105	108	104	177	255	408	325	285	176	176	148
11	111	105	108	103	174	243	426	307	277	178	173	150
12	110	105	108	102	166	270	362	317	271	183	171	151
13	109	105	106	102	160	280	333	327	264	265	170	150
14	109	183	106	103	154	771	364	313	259	226	167	149
15	109	242	106	103	265	1202	354	317	258	201	163	148
16	108	204	104	102	402	610	334	391	251	189	165	148
17	107	166	104	139	345	488	321	475	246	183	175	146
18	106	149	104	178	304	429	306	428	242	178	175	147
19	107	139	104	173	272	379	294	399	239	176	170	151
20	108	133	104	321	249	344	286	396	236	173	165	149
21	108	128	102	287	234	320	279	456	232	172	162	149
22	107	125	102	245	234	301	272	466	231	173	159	150
23	107	122	102	216	245	280	264	425	226	170	157	147
24	106	120	103	193	236	266	256	391	220	168	155	146
25	105	120	104	175	217	255	250	368	214	165	155	145
26	105	120	104	160	206	259	244	2159	213	225	153	145
27	105	120	104	152	198	259	243	774	209	296	153	144
28	105	120	104	145	190	269	281	653	206	247	152	144
29	105	120	104	142	---	290	280	571	202	220	151	143
30	105	118	106	137	---	290	265	508	198	202	150	143
31	105	---	106	133	---	297	---	464	---	191	150	---
MIN	105	104	102	102	132	174	229	245	198	165	150	143
MAX	115	242	118	321	402	1202	426	2159	437	296	245	151
AVG	109	126	107	144	212	328	291	481	272	195	173	148

DISCHARGE:

AC-FT 6718 7521 6595 8858 11758 20160 17310 29562 16155 11980 10631 8779

WATER YEAR EXTREMES: MINIMUM - 102 (DEC 21), MAXIMUM - 2159 (MAY 26), AVERAGE - 216

WATER YEAR TOTAL DISCHARGE: 156029 ACRE-FEET

Table 19: Average daily discharge, Bennett Spring gaging station, water year 1989-1990.

Major Springs

SUMMARY, WATER YEAR 1989 - 1990, BENNETT SPRING GAGING STATION (CORRECTED FOR SURFACE RUNOFF FROM SPRING HOLLOW)

DALLAS COUNTY: NE1/4 NW1/4 SEC. 1, T. 34 N., R. 18 W.
37 DEG 43 MIN 03 SEC NORTH LATITUDE, 92 DEG 51 MIN 26 SEC WEST LONGITUDE

LAND SURFACE ELEVATION: 866 FEET ABOVE MEAN SEA LEVEL. MEASURING POINT IS 864.71 FT ABOVE NATIONAL GEODETIC VERTICAL DATUM OF 1929.

RECHARGE AREA: 265 SQUARE MILES, 169600.0 ACRES

TYPE OF INSTALLATION: STEVENS DIGITAL WATER STAGE RECORDER INSTALLED MAY 16, 1987. PRIOR TO MAY 16, 1987 NONRECORDING STAGE, 41 YEARS OF RECORD. STATION OPERATED BY THE U. S. GEOLOGICAL SURVEY

AVERAGE DAILY DISCHARGE (CUBIC FEET PER SECOND), WATER YEAR 1989 - 1990

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	114	105	118	105	132	186	291	251	434	196	183	149
2	114	104	116	105	159	184	280	244	407	194	178	148
3	114	104	116	104	161	184	268	382	380	192	175	148
4	113	104	114	109	161	180	260	507	360	188	237	148
5	114	105	114	108	172	176	252	491	342	185	245	148
6	115	105	112	106	178	173	247	440	327	185	211	148
7	115	108	112	105	182	181	241	397	314	183	196	148
8	114	104	110	105	179	258	234	368	300	181	187	148
9	114	104	110	104	176	271	229	345	292	179	181	148
10	113	105	108	104	177	254	327	322	285	176	176	148
11	111	105	108	103	174	242	398	304	277	178	173	150
12	110	105	108	102	166	270	357	315	271	183	170	151
13	109	105	106	102	160	278	330	325	264	255	169	150
14	109	183	106	103	154	509	358	310	259	225	167	149
15	109	242	106	103	264	740	350	314	258	201	163	148
16	108	204	104	102	394	596	332	365	251	189	165	148
17	107	166	104	139	342	495	320	449	246	183	175	146
18	106	149	104	178	303	428	304	421	242	178	175	147
19	107	139	104	173	272	378	293	395	239	176	170	151
20	108	133	104	321	248	343	285	390	236	173	165	149
21	108	128	102	287	234	320	279	437	232	172	162	149
22	107	125	102	245	234	301	271	457	231	173	159	150
23	107	122	102	216	245	280	264	421	226	170	157	147
24	106	120	103	193	236	266	256	388	220	168	155	146
25	105	120	104	175	217	255	250	366	214	165	155	145
26	105	120	104	160	206	259	244	721	213	220	153	145
27	105	120	104	152	198	259	243	678	209	295	153	144
28	105	120	104	145	190	268	279	620	206	247	152	144
29	105	120	104	142	---	288	277	560	202	220	151	143
30	105	118	106	137	---	288	264	503	198	202	150	143
31	105	---	106	133	---	296	---	461	---	191	150	---
MIN	105	104	102	102	132	173	229	244	198	165	150	143
MAX	115	242	118	321	394	740	398	721	434	295	245	151
AVG	109	126	107	144	211	303	286	418	271	194	173	148
DISCHARGE:												
AC-FT	6718	7521	6595	8858	11730	18657	17024	25680	16136	11946	10627	8779
INCHES	0.48	0.53	0.47	0.63	0.83	1.32	1.20	1.82	1.14	0.85	0.75	0.62

WATER YEAR EXTREMES: MINIMUM - 102 (DEC 21), MAXIMUM - 740 (MAR 15), AVERAGE - 207.57
TOTAL DISCHARGE: 150271 ACRE-Feet, 10.63 WATERSHED INCHES

Table 20: Average daily discharge, water year 1989-1990, at Bennett Spring. Flow corrected for discharge of Spring Hollow upstream from Bennett Spring.

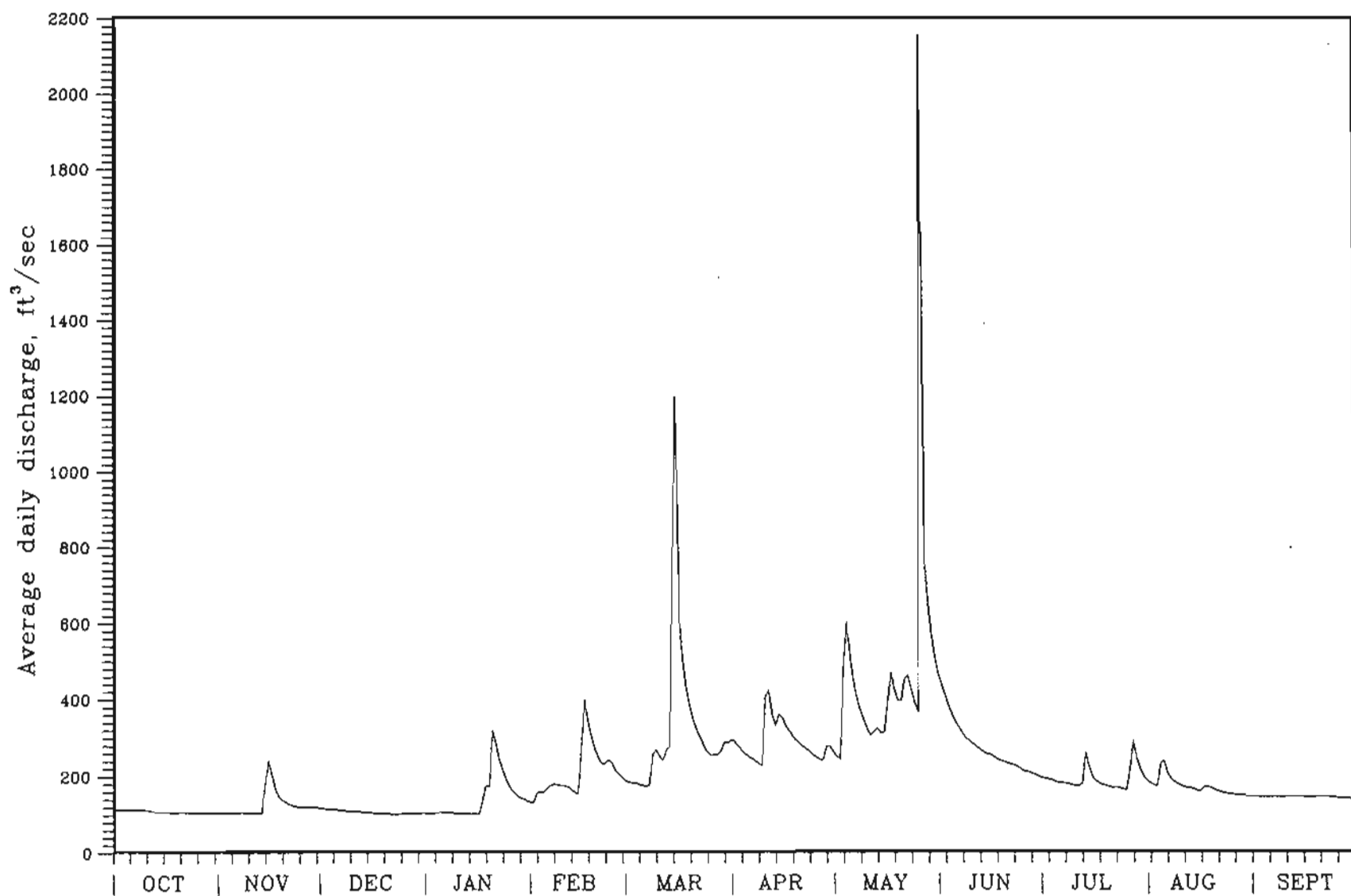


Figure 27: Average daily discharge hydrograph, Bennett Spring gaging station, water year 1989-1990. Data includes runoff from Spring Hollow.

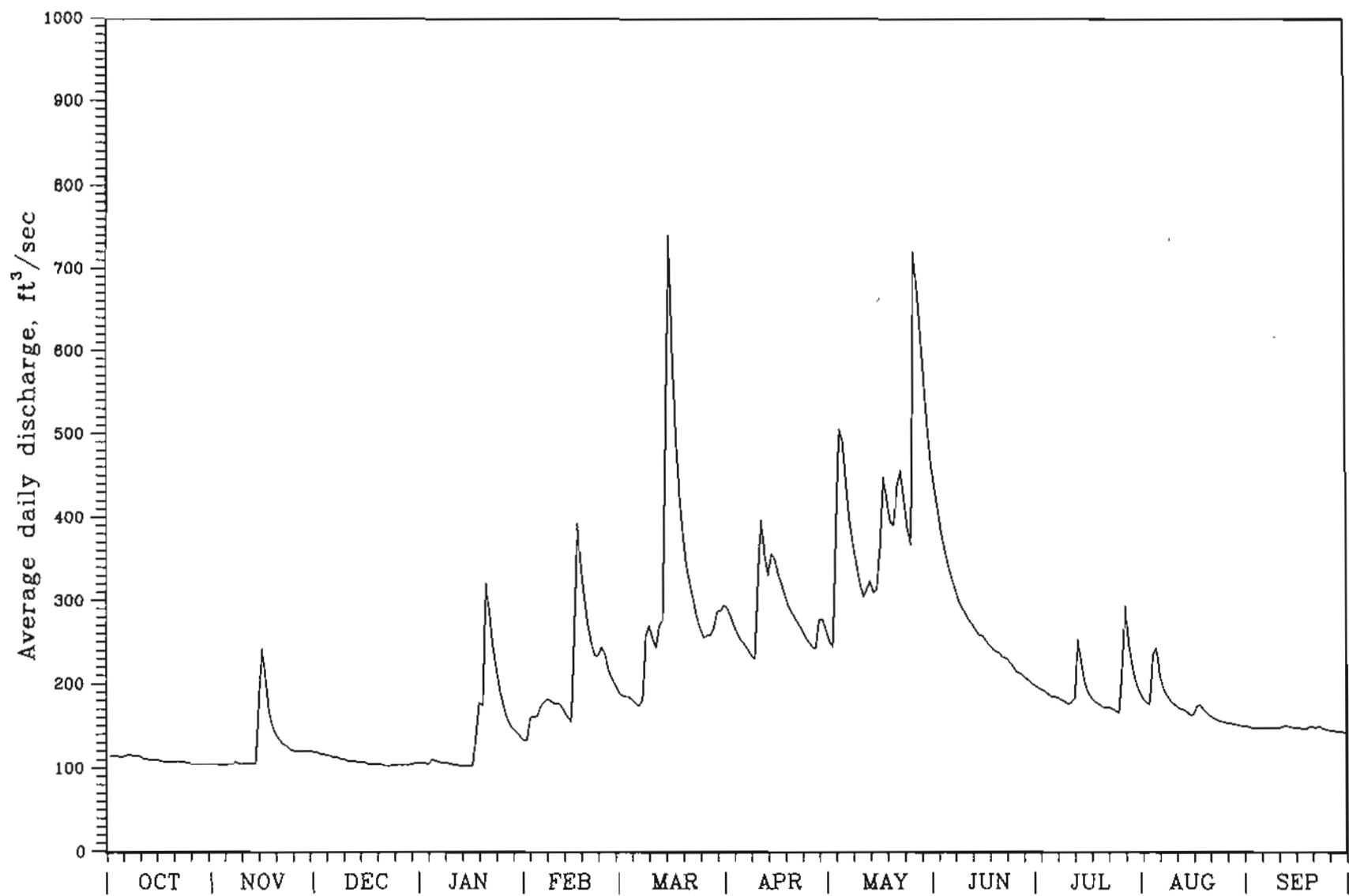


Figure 28: Average daily discharge hydrograph, Bennett Spring, water year 1989-1990. Data corrected for runoff from Spring Hollow upstream of Bennett Spring.

maximum discharge values were 4.57 ft³/sec and 5.06 ft³/sec, respectively. The spring flow was measured twice during this study. On April 18, 1990, during relatively wet weather, the spring measured 8.16 ft³/sec, and on September 25, 1990, after several weeks of dry weather, it measured 3.96 ft³/sec. Although the spring is small in

comparison to Bennett Spring, it has a well-sustained dry-weather base flow. Many springs of similar size have highly variable discharges. Sand Spring discharge does increase in response to local rainfall, but its relatively constant dry-weather flow makes it an interesting and somewhat unique spring.

FAMOUS BLUE SPRING **(NW¼ SEC. 36, T. 35 N., R. 18 W.)**

Famous Blue Spring in Dallas County is about 3,000 feet southwest of Sand Spring on the same side of the Niangua River. It rises from a 15-foot diameter pool developed in the Gasconade Dolomite in the bottom of a small hollow on the edge of the floodplain (photo 13). Water in the rise pool is normally quite clear, and it is possible to see 15 to 20 feet downward into the sand-bottomed bedrock conduit.

Missouri Speleological Survey divers Kurt Olson and David Porter made an exploratory dive into the spring on August 4, 1990. They found the orifice at the base of the rise pool to be nearly choked with logs and boards, but managed to circumvent the debris and continue exploration of the phreatic cave. The passage is high, narrow, and slopes steeply downward. The floor is coarse sand, but the walls are dolomite, heavily sculpted by solution. They managed to explore the spring conduit for about 100 feet, reaching a depth of about 61 feet where the sand floor came to within 1.5 feet of the ceiling. Here, sand from the floor is

kept in constant agitation by the velocity of the water, causing a billowing cloud of suspended sediment. A quiet pocket some 15 feet closer to the entrance has water moving vertically upward through the sand with enough velocity to suspend it several inches from the bottom of the pool (Porter, 1990; written communication).

Famous Blue Spring discharge was measured four times between 1933 and 1964. Minimum and maximum measured discharges were 2.39 ft³/sec and 4.44 ft³/sec, with an average of 2.99 ft³/sec (Vineyard and Feder, 1974). The spring was gaged twice during the present study. On April 18, 1990, during relatively wet weather, discharge was 8.05 ft³/sec, and on September 25, 1990, during dry weather, flow was 4.07 ft³/sec. Like Sand Spring, Famous Blue Spring has a well-sustained base flow even during very dry weather and responds to local precipitation. Its low and high flows do not vary as widely as many similar springs of comparable size.

SWEET BLUE SPRING **(NE¼ SEC. 30, T. 36 N., R. 17 W.)**

Sweet Blue Spring is on the east side of the Niangua River, west of Eldridge, in northwestern Laclede County. The spring rises from a deep pool covered with sand and gravel at the base of a low bluff of Gasconade Dolomite. The Niangua River, only a few feet lower and 150 feet west of the spring, inundates the spring during floods. Sweet Blue Spring, a losing stream draining several square miles, intersects with Sweet Blue Spring branch at the river's edge.

Divers have been unable to penetrate an appreciable distance into the phreatic conduit supplying the spring, but have reported the water rising through the gravel floor of a circular room some 15 feet in diameter and 12 feet high that is reached through a cave entrance 10 feet wide by 5 feet high at the bottom of the spring basin. The base of the gravel floor in the rise room is about 47 feet deep, and ascending water creates a gravel plume 3 to 5 feet high (Vineyard and Feder, 1974).



Photo 12. Sand Spring rises through the bottom of a pond on the northwest side of the Niangua River near Bennett Spring State Park. From the pond, its flow is channelled through a concrete sluice and past a water wheel before it enters the Niangua River a few hundred feet away.



Photo 13. Famous Blue Spring rises from a water-filled cave several hundred feet north of the Niangua River. Its recharge area, which is shared with Sand Spring, lies mostly to the south on the opposite side of the Niangua River. Water discharging from both springs must cross under the Niangua River.

Six discharge measurements taken between 1925 and 1964 showed Sweet Blue Spring's discharge to average 13.2 ft³/sec, with minimum and maximum measured flows of 11.0 ft³/sec and 15.6 ft³/sec (Vineyard and Feder, 1974). More recent work (Harvey et al., 1983) shows this value may be too low. Four discharge measurements taken

between June, 1976, and August, 1977, averaged 28.5 ft³/sec, with minimum and maximum measured flows of 20.7 ft³/sec and 47.2 ft³/sec. Apparently, data in Vineyard and Feder (1974) reflect primarily low base-flow conditions. Average flow of the spring is probably about 20 ft³/sec.

JOHNSON-WILKERSON SPRING (SE 1/4 SEC. 2, T. 32 N., R. 19 W.)

Johnson-Wilkerson Spring in southern Dallas County is one of several significant groundwater outlets found during this study that were previously unreported. Water rises from alluvium in at least two locations on the east side of the Niangua River west of Conway, Missouri. One spring rise is in the channel of a small ephemeral watershed about 1,500 feet from the Niangua. The other major rise is about 600 feet from the river and south of the channel draining the upstream outlet; their flows merge and enter the Niangua about 300 feet upstream from the Route M bridge and 1,200 feet downstream from the mouth of Jones Creek. Here, the Niangua River flows on

Roubidoux Formation with Jefferson City Dolomite underlying the upland area.

Little information exists on the spring; Skinner (1979) mentions the spring and supplies its name, but it is not shown on the Long Lane 7.5 minute quadrangle map nor listed in Springs of Missouri. Its discharge was measured once during this study. On September 25, 1990, flow was 3.71 ft³/sec. Flow estimates made during 1989 and 1990 indicate an average flow of about 3 to 5 ft³/sec. The spring has a well-sustained base flow even during dry weather. Wet-weather discharges are considerably higher, and flows exceeding an estimated 12 ft³/sec have been observed.

JAKE GEORGE SPRINGS (SW 1/4 SEC. 13, T. 32 N., R. 19 W.)

A few hundred yards downstream of the Webster-Dallas County line, flow characteristics of the Niangua River change considerably. Though there is perennial flow upstream for several more miles, dry-weather flows are quite small, often less than 1 ft³/sec. Over a distance of a few hundred feet, water from several groundwater outlets increase the Niangua River low-flow discharge several hundred percent. Jake George Springs enter the Niangua from several places on the floodplain. Two distinct spring rises occur on the east side of the river; one is an alluvial rise pool, the other is from bedrock openings in the Roubidoux Formation on the east valley wall. Another alluvial rise pool lies a few hundred feet downstream on the west side of the river. Spring branches from all three rises enter the river within about a 200-foot

reach. A short distance upstream, groundwater enters the river from a 200-foot line of seeps discharging from a low alluvial terrace.

Jake George Springs are not shown on the Beach 7.5 minute quadrangle, and little information exists for the springs. Skinner (1979) lists the spring, but provides no additional information. Harvey et al. (1983) measured the springs in November, 1975, and found the river discharge to increase from 5.5 ft³/sec to 25 ft³/sec, an increase of 19.5 ft³/sec, due to inflow from the springs. On November 3, 1990, during relatively dry weather, river discharge upstream from the springs was 1.68 ft³/sec, and downstream the discharge was 15.8 ft³/sec, an increase of 14.1 ft³/sec. High-flow characteristics of the springs are unknown.

Even though there are several distinct outlets, temperature, fluorometric, and specific conductivity characteristics indicate the water is from a common source. Temperature and conductivity of the springs were measured several times and did not vary between individual rises. Background spectrofluorograms of the springs were also nearly identical.

There are other springs upstream from Jake George Spring in the Niangua River basin, but all are much smaller. In very dry weather, flow of the

Niangua ceases at losing zones near the East Fork-West Fork confluence about 3.5 miles upstream. Between Route Y and Jake George Springs, some water enters the river from small springs and there are several large pools, but significant flows do not begin before Jake George Springs.

Water discharging from Jake George Springs likely rises from bedrock openings in the Roubidoux Formation beneath the alluvium. Local residents report that floods will alter the river channel, and change the locations where some of the springs rise.

HAHATONKA SPRING **(SW¹/₄ SEC. 2, T. 37 N., R. 17 W.)**

Hahatonka Spring, in Ha Ha Tonka State Park, is in Camden County outside of the study area for this report. However, since previous work shows the spring receives recharge from within the study area, it was monitored as part of the dye tracing study.

With an average discharge of about 77 ft³/sec, it is the largest spring in Camden County. Minimum and maximum recorded flows are 43 ft³/sec and 175 ft³/sec (Vineyard and Feder, 1974). The spring discharges from a phreatic cave developed in the upper part of the Eminence Dolomite. Lower Gasconade Dolomite and the Gunter Sandstone member crop out in the valley walls around the spring branch. The spring rises at the head of a narrow, deep valley that likely developed by

collapse rather than by surface erosion. A bedrock island, containing several caves and heavily weathered bedrock, divides the spring branch a few hundred feet downstream of the spring. Beyond the island, spring flow enters the Niangua arm of Lake of the Ozarks.

Hahatonka Spring is one of many karst features occurring in the immediate area. Several major sinkholes, one containing a large natural bridge, lie within a few hundred yards east of the spring. River Cave, which pirates flow from surface drainage and channels it into the Hahatonka Spring conduit system, is 2,000 feet to the northeast. Divers entering the spring have made the underwater connection with River Cave (Porter, 1990; personal communication).

BIG SPRING **(NE¹/₄ SEC. 6, T. 32 N., R. 15 W.)**

Big Spring on the Osage Fork of the Gasconade River is likely the largest spring in Laclede County. The spring rises from a low, wide, bedrock opening in Gasconade Dolomite at the bottom of a deep pool on the west side of the river. The spring is shown on the Russ 7.5 minute quadrangle map, but is actually about 400 feet upstream of where shown on the map. Because it rises directly in the river, its flow can only be measured by subtracting river flows measured upstream and downstream of the spring. It has been measured only a few times during relatively low flow periods. Big

Spring has a low base flow of about 17 ft³/sec, but average flow is likely significantly higher. During wet weather, when the Osage Fork is several feet above low-flow stage, Big Spring's clearer water exits the conduit with enough hydrostatic force to create a sizable boil, and divert the river water away from the orifice.

Divers Roger Gliedt, Kurt Olson, and David Porter have made two underwater explorations of Big Spring. They found the water to emerge from a low, narrow opening at the base of a Gasconade

Dolomite bluff at a depth of about 10 feet. The 2- to 3-foot high, 4-foot wide submerged cave passage trends southeast, and was followed for a distance of about 250 feet to a depth of 21 feet below river level. Exploration ended in an 8-foot diameter, 5-foot high room where ceiling breakdown restricted passage size. A second passage was found leading southwest from the main passage. Along this 250-foot long passage, depth

increased from 22 feet to 31; the shallow part of the passage was floored with breakdown, but the ceiling in the deeper section had not collapsed. Interestingly, flow in this passage was toward the end of the passage, and not toward the spring outlet (Porter, 1990; written communication). Further diving will be necessary to more fully understand the flow relationships in this spring.

RANDOLPH SPRING **(NE $\frac{1}{4}$ SEC. 6, T. 32 N., R. 15 W.)**

Immediately downstream of Big Spring is a long gravel-bar island that divides the Osage Fork. Randolph Spring flows into the Osage Fork from the southwest side of the river at the downstream end of the island. The spring flows from a bedding-plane opening at the base of a 50-foot bluff of Gasconade Dolomite. The outlet is some 5 feet above and 50 feet from river. Though not shown on the Russ 7.5 minute quadrangle map, Randolph Spring discharges a considerable quantity of water. The spring was previously unreported, and is not listed in Springs of Missouri (Vineyard and Feder, 1974). No flow measurements exist, but during low-flow conditions estimated discharge is about 1 to 2 ft³/sec. Wet weather flows are considerably higher.

Missouri Speleological Survey divers David Porter and Roger Gliedt were able to enter the spring outlet and explore the phreatic conduit a short distance. They were able to penetrate the conduit about 50 feet, to a depth of 10 feet, where exploration ended in a small, gravel-floored room. Here, water rises through the gravel but no enterable passages continue.

Although Randolph Spring is less than 1,200 feet downstream from Big Spring, the two appear to be hydrologically separate. Temperature and specific conductivity measurements at both springs show different water temperatures and dissolved solids contents. Temperature at Randolph Spring varies considerably with local rainfall, indicating relatively nearby discrete recharge.

CLIFF SPRING **(NW $\frac{1}{4}$ SEC. 9, T. 35 N., R. 14 W.)**

Cliff Spring, in Laclede County, discharges from bedding-plane openings in the Gasconade Dolomite at the base of the valley wall on the west side of the Gasconade River. The spring flow has been measured only a few times, and it likely has an

average discharge of 2 to 4 ft³/sec. Flow, temperature, and water-quality measurements indicate that recharge is very local and rapid. Temperatures as low as 50° F. were measured during wet weather in early spring, 1990.

GROUNDWATER TRACING

INTRODUCTION

Groundwater recharged through sinkholes and losing streams typically follows well-defined flow paths. The karst processes that formed these discrete recharge features simultaneously created the well-integrated labyrinth of bedrock conduits or cave-like openings that transport water to springs. Water entering the subsurface through sinkholes and losing streams moves rapidly through relatively large openings, making it possible to trace this type of groundwater movement using specially developed techniques.

For more than 30 years, fluorescent dyes have been used to determine the outflow points of water disappearing into the subsurface through losing streams and sinkholes. Dye tracing is an extremely valuable technique; it allows a physical connection to be established between groundwater recharge and discharge. Dye tracing consists of injecting harmless fluorescent dye into water entering a sinkhole or losing stream, then monitoring for that dye at springs or gaining streams where it may reappear.

To be useful for groundwater tracing, dyes must be water-soluble, have sufficiently low adherence to earth materials, be environmentally safe, and be detectable in low concentrations. Several dyes have most of these characteristics, but two in particular, Rhodamine WT and fluorescein, have been used for the vast majority of dye traces conducted in the Ozarks, and were used for all of the dye tracing in the Bennett Spring area. Fluorescein is marketed under several names by different companies, and two brands of fluorescein dye were used. In this report, fluorescein refers to Pylam Pyla-tel Fluorescent Yellow Dye. Uranine C, fluorescein marketed by Chemcentral Dye-stuffs, was also used. Although nearly identical, the dyes are referenced separately in this report. Rhodamine WT is purchased in liquid form, and has a 20-percent dye content; fluorescein and Uranine C are dry powders.

Though Rhodamine WT and fluorescein dyes are very colorful, and visible to the naked eye in relatively low concentrations, their fluorescence is the property that makes them most useful for groundwater tracing. The proper wavelength of

light directed on a fluorescent dye excites some of its electrons to a higher energy state. As the electrons return to ground state, photons of light are emitted. The emitted energy has a longer wavelength than that absorbed. A spectrofluorophotometer is used to excite the fluorescent material, and detect and quantify the resulting fluorescence.

There are several ways that springs can be sampled for dye content. Water samples can be collected and analyzed for dye content. This type of sampling has the advantages of simplicity and low cost, but unless frequent samples are taken the peak of the dye cloud may be missed. Relatively small quantities of dye are injected into the subsurface and there is tremendous dilution in many spring systems. It is quite possible that dye content in the spring water may be below detection limits at times other than for a short time at or near the peak of dye passage. Automated water samplers can also be used, and alleviate the problem of sampling frequency. Typically these devices can collect up to about 30 samples at a user-specified time interval. Automated water samplers provide excellent information as to dye arrival time and dye content, but they are expensive pieces of equipment and can malfunction during freezing weather.

The dye monitoring technique most often employed, and used exclusively in this study, uses activated coconut charcoal to adsorb dye if it is present in the water. Small (2 inch by 3 inch) fiberglass screen wire packets containing about 15 cm³ of 6-14 mesh activated coconut charcoal are placed at potential dye-recovery sites. Activated charcoal packets have several advantages over water samples. They adsorb dye continuously. If dye is present in very low quantities, even below water-sample detection limits, activated charcoal will effectively concentrate the dye in the charcoal. The packets can be changed at frequent intervals for accurate time-of-travel data, or can be left in place for several weeks if necessary. It is important to place the activated charcoal packets so there is constant water movement through them, but if water velocity is too high the packets can be torn. Copper and plastic-coated steel wire were used to attach the packets to trees, roots,

large rocks, or other anchor points. Packets were generally replaced at one to two week intervals, depending on the site. During two dye traces, packets at Bennett Spring were changed daily to yield more accurate time-of-travel data.

Dye analyses were performed at the Division of Geology and Land Survey's Environmental Tracing Laboratory in Rolla, Missouri. Here, the packets were washed under a high-velocity water jet to remove sediment and extraneous material from the packets. The packets are opened, and the charcoal placed in plastic specimen containers. The charcoal is then elutriated with a 5 percent solution of ammonium hydroxide in ethyl alcohol to release the dye from the charcoal. After an hour, 4 ml of elutriant is pipetted from the charcoal, placed in a sample holder, and analyzed.

A Shimadzu Model RF-540 scanning spectrofluorophotometer was used to determine the presence of fluorescent dye in the samples. The instrument is interfaced to an IBM PC, which controls the spectrofluorophotometer and records digital output data. Spectrofluorograms are printed from the processed output data. Fluorescein and Uranine C, in a 5 percent solution of ammonium hydroxide in ethyl alcohol, have excitation peaks of about 500 nanometers (nm) and emission peaks of about 517 nm. Rhodamine WT has an excitation peak of about 550 nm and an emission peak of 568 nm. The spectral characteristics of the two dyes allow both to be used in the same area simultaneously; both can be analyzed during a single sample scan using the spectrofluorophotometer.

To analyze for dye content, the excitation and emission monochromators on the spectrofluorophotometer are set for a 17 nm spacing. Starting excitation and emission wavelengths are set at 475 nm and 492 nm, and ending excitation and emission wavelengths are set at 575 nm and 592, respectively. During the sample scan, the monochromators, which control the light wavelengths emitted and received, are advanced synchronously to maintain a 17-nm spacing. If the dyes are present in the sample, fluorescence will be greatest when the excitation and emission monochromator wavelengths coincide with the excitation and emission peaks of the dyes. The spectrofluorograms will con-

tain an emission peak at about 517 nm for fluorescein and Uranine C, and 568 nm for Rhodamine Wt. Scan results are compiled by the computer, and graphically depicted on the spectrofluorograms. Figure 29 shows spectrofluorograms from a sample containing no dyes, a sample containing fluorescein, a sample containing Rhodamine Wt, and a sample containing both dyes.

Dye tracing in the study area began with placing activated charcoal packets in springs and gaining streams to quantify background fluorescence. Certain naturally occurring fluorescent materials can be present in the environment. Also, the dyes used for tracing have other commercial applications; fluorescein is used as a coloring agent in certain household products and automotive antifreeze. Background fluorescent data are used to determine if extraneous fluorescent materials are present that could interfere with a dye trace.

Dye injection locations must be carefully selected. The site must be a point of known surface-water loss. Additionally, there must be water available to carry the dye from the surface into the subsurface. With sinkhole injection sites, this requires injecting the dye into runoff following heavy precipitation or hauling water to the sinkhole. Most losing streams are completely dry for long reaches in dry weather, but many have small springs along their reaches or on their tributaries that provide flow for a short distance before losing into the subsurface. These are generally satisfactory dye injection sites. Many times, following precipitation, losing streams will carry water.

An excellent time to inject dye into a losing stream is when stream flow is receding before the stream becomes completely dry.

The amount of dye necessary for a successful groundwater dye trace varies depending on injection site conditions, local rainfall, anticipated travel distance, and recovery-site flow characteristics. Traces performed during this study typically used from one to six pounds of fluorescein or Uranine C, or up to 3.5 liters of Rhodamine Wt (20%) for travel distances from less than a mile to almost 20 miles. In one case, less than one liter of Rhodamine WT (20%) was used for a 13.8-mile trace.

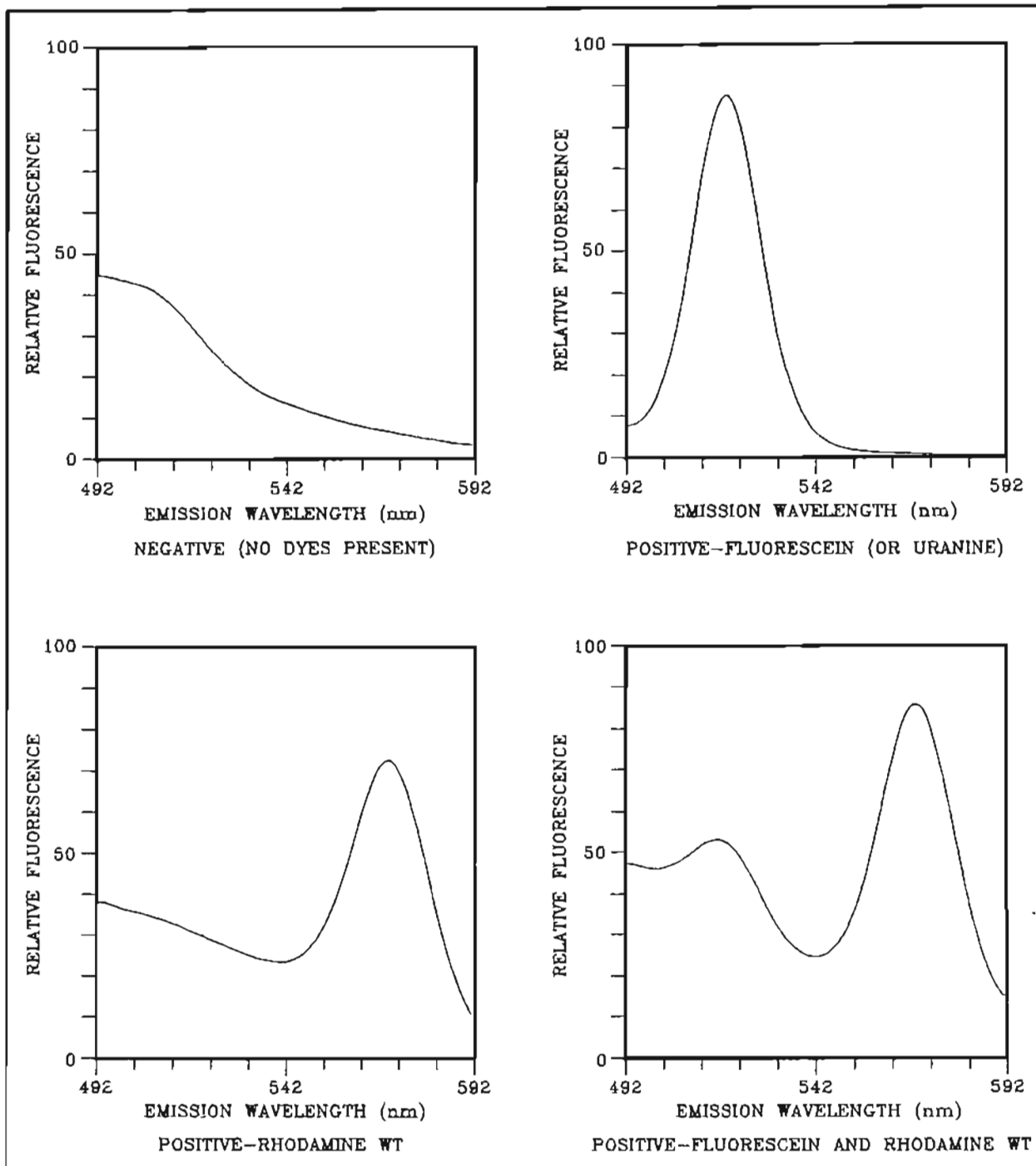


Figure 29: Spectrofluorograms of activated charcoal samples containing no dye, fluorescein dye, and Rhodamine WT dye.

During this study, 18 dye traces to nine springs from 14 dye injection sites were completed. In four instances, dye from a single injection site was recovered at more than one spring. In these cases, each spring that received dye is considered a separate dye trace, so four of the injection sites accounted for eight dye traces. Dye from the other 10 injection sites was recovered at single springs. Dye recovery packets were placed at 45 sites throughout the study area (fig. 30). Table 21 lists the sites, their reference numbers, and type of monitoring. Some of the sites were monitored nearly continuously throughout the study; others were monitored temporarily in conjunction with a particular dye trace. In all, 586 dye recovery packets were collected and analyzed. With most of the traces, dye was recovered within two to four weeks after it was injected. However, since only two types of dye were used, time had to be allowed

for the dye to be flushed from the groundwater system before another trace could be initiated. Depending on the amount of dye used, discharge of the spring, and precipitation, it took several weeks to several months before residual dye was flushed from the spring systems.

Figure 31 shows injection and recovery sites for dye traces conducted in the study area. The map lines used to connect injection with recovery sites are straight, where possible, but are not meant to represent the actual path of groundwater movement. Traces DT 1 through DT 18 were conducted during this study; previous traces are referenced by investigator and year. Tables 22 and 23 list injection and recovery site names and locations, injection and first recovery dates, and other physical data. Highlights of the individual traces are presented in the following section.

SUMMARIES OF INDIVIDUAL DYE TRACES

UPPER FOURMILE CREEK TRACE, DT 1

Fourmile Creek is a losing stream throughout much of its reach, but contains two significant reaches where it is a gaining stream. One gaining reach is in the upstream part of the watershed. Here, the stream flows on upper Roubidoux Formation, but the uplands are underlain by Jefferson City Dolomite. During dry weather, flow disappears into the subsurface about a mile downstream of Route B in Dallas County near Long Lane.

On June 27, 1989, six pounds of Uranine C was placed in Fourmile Creek about 200 feet upstream of the water-loss zone. Light rain

was occurring at the time, but there had been little rainfall during the preceding weeks. There was about 30 gpm flowing in Fourmile Creek where the dye was injected; it disappeared into the subsurface at a shallow pool rimmed by bedrock. Downstream were scattered pools, but there was no flow for at least 2 miles. Upstream from this point, Fourmile Creek drains 3.32 mi². The dye was recovered 8.5 miles to the northeast, between 14 and 22 days later, at Bennett Spring. Dye recovery packets placed at a gaining reach in middle Fourmile Creek and at the mouth of the creek did not contain dye.

JONES CREEK TRACE, DT 2

Jones Creek drains a 34.3 mi² area between Conway, Missouri, and the Niangua River. It is a gaining stream throughout much of its length, but contains a losing zone about 1.5 miles long in its middle reach. Its two major tributaries, Starvey Creek and Goose Creek,

contain upper-watershed gaining reaches, but lose flow in their downstream reaches. Much of the uplands are underlain by Jefferson City Dolomite, but Jones Creek flows on Roubidoux Formation throughout most of its length.

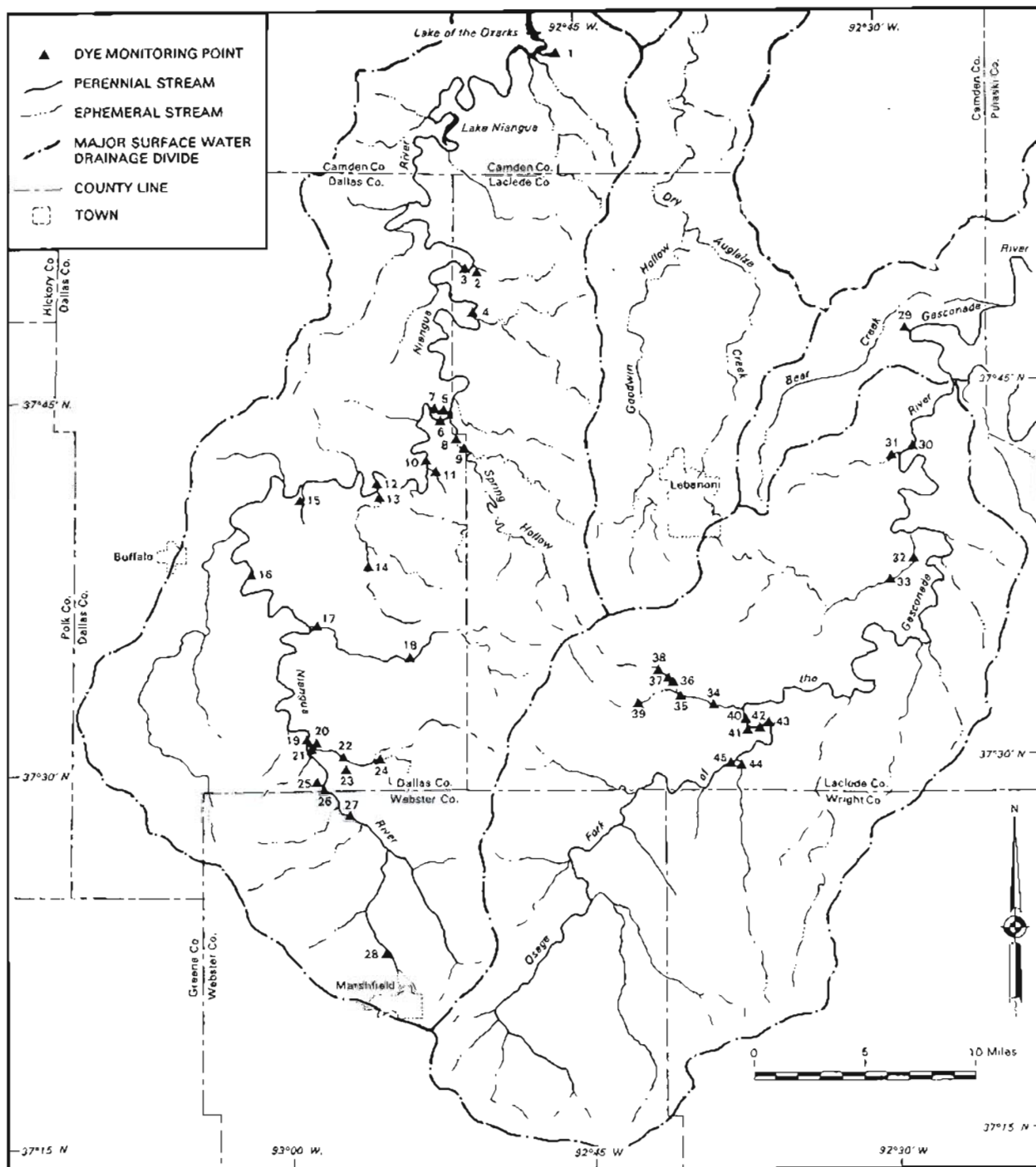


Figure 30: Dye monitoring sites.

MAP NUMBER	DYE MONITORING SITE NAME	LOCATION	TYPE OF MONITORING*
1	Hahatonka Spring	SW 1/4 Sec. 2, T. 37 N., R. 17 W.	C
2	Sweet Blue Spring	NE 1/4 Sec. 30, T. 36 N., R. 17 W.	I
3	Niangua River near Sweet Blue Spring	NE 1/4 Sec. 30, T. 36 N., R. 17 W.	T
4	Niangua River at Prosperine Access	SW 1/5 Sec. 5, T. 35 N., R. 17 W.	T
5	Sand Spring	SE 1/4 Sec. 25, T. 35 N., R. 18 W.	C
6	Niangua River above Bennett Spring	NE 1/4 Sec. 36, T. 35 N., R. 18 W.	I
7	Famous Blue Spring	NW 1/4 Sec. 36, T. 35 N., R. 18 W.	C
8	Bennett Spring (3 sites)	NW 1/4 Sec. 1, T. 34 N., R. 18 W.	C
9	Spring Hollow above Bennett Spring	NE 1/4 Sec. 1, T. 34 N., R. 18 W.	I
10	Niangua River at Moon Valley Access	SW 1/4 Sec. 2, T. 34 N., R. 18 W.	I
11	Unnamed creek at Moon Valley Access	SW 1/4 Sec. 2, T. 34 N., R. 18 W.	T
12	Niangua River below Fourmile Creek	NE 1/4 Sec. 8, T. 34 N., R. 18 W.	I
13	Fourmile Creek at mouth	NE 1/4 Sec. 8, T. 34 N., R. 18 W.	I
14	Fourmile Creek near Fourmile Cemetery	NW 1/4 Sec. 24, T. 34 N., R. 18 W.	T
15	Benton Creek near mouth	NW 1/4 Sec. 11, T. 34 N., R. 19 W.	T
16	Niangua River at Missouri Highway 32	SW 1/4 Sec. 28, T. 34 N., R. 19 W.	I
17	Dousinbury Creek at Route JJ	SE 1/4 Sec. 12, T. 33 N., R. 19 W.	I
18	Dousinbury Creek at Route P	SE 1/4 Sec. 15, T. 33 N., R. 18 W.	T
19	Niangua River above Route M	SE 1/4 Sec. 2, T. 32 N., R. 19 W.	C
20	Johnson/Wilkerson Spring	SE 1/4 Sec. 2, T. 32 N., R. 19 W.	C
21	Jones Creek near mouth	NE 1/4 Sec. 11, T. 32 N., R. 19 W.	T
22	Jones Creek at Gunter farm	SW 1/4 Sec. 8, T. 32 N., R. 18 W.	T
23	Gunter Spring	NW 1/4 Sec. 17, T. 32 N., R. 18 W.	T
24	Starvey Creek near mouth	SW 1/4 Sec. 10, T. 32 N., R. 18 W.	T
25	Jake George Springs (3 sites)	SE 1/4 Sec. 13, T. 32 N., R. 19 W.	T
26	Niangua River above Jake George Springs	SW 1/4 Sec. 13, T. 32 N., R. 19 W.	T
27	Niangua River at Gourley Ford Bridge	NE 1/4 Sec. 30, T. 32 N., R. 18 W.	I
28	Vineyard Spring	NW 1/4 Sec. 28, T. 31 N., R. 18 W.	T
29	Cliff Spring	NW 1/4 Sec. 9, T. 35 N., R. 14 W.	I
30	Osage Fork at Hull Ford Access	NW 1/4 Sec. 4, T. 34 N., R. 14 W.	T
31	Mill Creek at mouth	NE 1/4 Sec. 5, T. 34 N., R. 14 W.	T
32	North Cobb Creek at Missouri Highway 32	NW 1/4 Sec. 28, T. 34 N., R. 14 W.	T
33	North Cobb Creek, county rd. above Mo. 32	NW 1/4 Sec. 32, T. 34 N., R. 14 W.	T
34	Brush Creek, first county rd. above mouth	NW 1/4 Sec. 36, T. 33 N., R. 16 W.	C
35	Brush Creek at Route PP	SE 1/4 Sec. 27, T. 33 N., R. 16 W.	T
36	Selva Hollow at Route C	SW 1/4 Sec. 22, T. 33 N., R. 16 W.	T
37	O'dell Spring #2	SE 1/4 Sec. 21, T. 33 N., R. 16 W.	T
38	O'dell Spring #1	SE 1/4 Sec. 21, T. 33 N., R. 16 W.	T
39	Brush Creek near Bear Thicket Church	NE 1/4 Sec. 32, T. 33 N., R. 16 W.	T
40	Osage Fork below Randolph Spring	SE 1/4 Sec. 31, T. 33 N., R. 15 W.	C
41	Randolph Spring	NE 1/4 Sec. 6, T. 32 N., R. 15 W.	I
42	Big Spring	NE 1/4 Sec. 6, T. 32 N., R. 15 W.	I
43	Osage Fork above Big Spring	NW 1/4 Sec. 5, T. 32 N., R. 15 W.	T
44	Parks Creek at Route J	SW 1/4 Sec. 7, T. 32 N., R. 15 W.	T
45	Osage Fork at Route J	SW 1/4 Sec. 7, T. 32 N., R. 15 W.	T

* C Continuous dye-monitoring site

I Intermittent dye-monitoring site

T Temporary dye-monitoring site

Table 21: Dye monitoring site names, locations, and types of monitoring.

During dry weather, upper Jones Creek loses flow into the subsurface about 1 mile upstream of Route M in Dallas County, some 4 miles west of Conway. On August 30, 1989, one pound of fluorescein dye was injected into Jones Creek at this water-loss zone. Flow immediately upstream was about 30 gpm. Dye entered the subsurface at a bedrock-floored pool near where a fault crosses the creek. Upstream from the dye injection site, Jones Creek drains 11.1 mi².

Dye recovery packets were placed at several small springs along lower Jones Creek, in the

creek near its mouth, in the Niangua River at Route M about 1,500 feet downstream of its confluence with Jones Creek, and at major springs in the study area. None of the sites along Jones Creek showed dye, but fluorescein was recovered in the Niangua River at Route M between five and 34 days after injection. A spring branch was found entering the Niangua River from the east between Route M and the mouth of Jones Creek. Dye recovery packets placed in this spring branch, which carries flow from Johnson-Wilkerson Spring, contained the dye. The spring was previously unreported.

CAVE CREEK TRACES, DT 3 AND DT 4

Cave Creek drains a 13.3 mi² area in Dallas and Laclede counties on the east side of the Niangua River north of Highway 32 and west of Route OO. The creek intersects the Niangua River a few miles upstream of Bennett Spring, but provides no flow except during high-runoff periods. At its mouth, the channel is irregular, contains coarse gravel and boulders, and shows signs of infrequent flow. Higher elevations in the watershed are underlain by Roubidoux Formation, but the channel is developed mostly in Gasconade Dolomite.

About 3.5 miles south of Bennett Spring, at the only county road that crosses Cave Creek, flow from small, upper-valley springs in an unnamed northern tributary enters the Cave Creek valley. Flow reaches the Cave Creek floodplain, but disappears into the gravel before it reaches the channel. On September 6, 1989, 3.5 liters of Rhodamine WT (20%) dye was injected into the

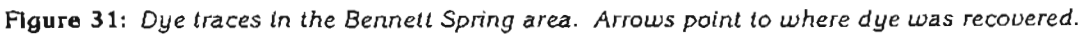
10-gpm flow disappearing into Cave Creek alluvium. Dye was recovered at Sand Spring, 4.7 miles north, 28 to 34 days after injection. Famous Blue Spring, a few thousand feet southwest of Sand Spring, was not initially monitored, but dye recovery packets placed there 75 days after injection showed strong Rhodamine WT content. Rhodamine was detectable at both springs for the next nine months.

It is interesting to note that both Sand Spring and Famous Blue Spring are on the opposite side of the Niangua River from where dye was injected into Cave Creek. Dye recovery packets placed in the Niangua River at Moon Valley, upstream from Sand and Famous Blue springs but downstream from the mouth of Cave Creek, showed no dye. To emerge at Sand Spring and Famous Blue Spring, recharge from Cave Creek must cross beneath the Niangua River.

EAST FORK NIANGUA RIVER TRACES, DT 5 AND DT 6

Though a gaining stream throughout most of its reach, the Niangua River contains a major water-loss zone in the upper watershed north of Marshfield in Webster County, where the East Fork and West Fork merge. Seepage runs by the U.S. Geological Survey (Harvey et al., 1983) show both forks lose flow, but water loss is most significant on the East Fork Niangua River. Nearly all of the East Fork is

a gaining stream, but about a mile upstream of the West Fork confluence, below several beaver dams, flow disappears into the gravel streambed. Except during wet weather, the channel remains dry for the next mile downstream. Jefferson City and Cotter dolomites form the bedrock surface through most of the watershed, but downstream from I-44 the creek is in Roubidoux Formation.



On November 21, 1989, 3.5 liters of Rhodamine WT (20%) dye was injected into the streambed of the East Fork Niangua River about 6 miles north of Marshfield and a mile upstream from West Fork. In the quarter-mile reach upstream from the injection site, East Fork was losing an estimated 0.5 ft³/sec. Upstream, East Fork Niangua River drains 24.9 mi². The dye disappeared into the subsurface at a discrete point downstream of the lowermost beaver dam within 10 minutes after injection. Downstream, there was no flow on either the East Fork or the West Fork, and for at least 0.25 mile downstream of Route Y.

Dye was first recovered between 9 and 14 days later in the Niangua River upstream from Route M.

A dye recovery packet placed in the Niangua River at Gourley Ford Bridge, the only river crossing between Route Y and Route M, did not contain dye. Jake George Springs, between Gourley Ford Bridge and Route M, are the only major groundwater outlet in this reach, and are the likely outflow points of the dye.

Between 14 and 27 days after injection, dye also began emerging at Bennett Spring. From the injection site to Jake George Springs is about 4.9 miles; the straight-line distance to Bennett Spring is 19.3 miles. Dye from the trace was detectable in the Niangua River at Route M and at Bennett Spring until early February, 1990.

STEINS CREEK TRACE, DT 7

Steins Creek is a major losing-stream tributary of the Osage Fork of the Gasconade River. It drains a 44.5 mi² area east of Grove Spring and south of Orla, Missouri, on the south side of the Osage Fork. There are few places along Steins Creek where dry-weather flow occurs; a few small springs provide minor flow for short reaches where the stream travels on Jefferson City Dolomite. Otherwise, the creek is usually dry from headwaters to mouth.

On January 11, 1990, Dave Hoffman, Division of Geology and Land Survey, injected 15 pounds of fluorescein into Steins Creek downstream of a small spring. Flow entered the subsurface within a few hundred feet downstream. Upstream, Steins Creek drains about 5.6 mi². This trace was in-

tended to not only show where flow lost in Steins Creek watershed reappears, but to help delineate a major groundwater divide. Earlier dye tracing by the Division of Geology and Land Survey showed that flow lost in Gasconade River tributaries a few miles south of Grove Spring reappears at springs in the North Fork River basin.

Dye was recovered at Big Spring, on the Osage Fork, 10.4 miles northwest of the injection site. Accurate travel-time data are not available, but the dye reappeared less than 41 days after injection. High flows on the Osage Fork, from precipitation in late January and February, 1990, made it difficult to retrieve dye recovery packets for several weeks. Dye was detectable at Big Spring for almost six months.

NORTH COBB CREEK TRACE, DT 8

North Cobb Creek, with a drainage area of 53.3 mi², is a major losing stream on the north side of the Osage Fork, and drains the area southeast of Lebanon. For about 6 miles upstream from its mouth, it is a gaining stream and there is nearly perennial flow. Upstream from here, though, groundwater levels are below the valley bottom, and the stream carries flow only briefly after heavy precipitation. Roubidoux Formation directly underlies North Cobb Creek essentially from head-

waters to mouth. In the downstream reach where it is a gaining stream, the Roubidoux is not deeply weathered and Jefferson City Dolomite underlies the uplands. However, in the upstream part of the watershed where North Cobb Creek is a losing stream, the Roubidoux is deeply weathered and contains numerous sinkholes. Though much of the runoff in North Cobb Creek watershed is lost into the subsurface, heavy precipitation can generate significant runoff. In May, 1990, a storm with

locally as much as 6 inches of rainfall, caused severe flooding and destroyed the Highway 32 bridge crossing lower North Cobb Creek.

On February 27, 1990, 3.5 liters of Rhodamine WT (20%) was injected into the bed of North Cobb Creek at its confluence with South Fork North Cobb Creek, about 4.5 miles southeast of Lebanon. Small springs a short distance upstream of the injection point provide a few gallons of water per minute flow, but it disappears into the streambed within a short distance downstream. There is one sizable, perennial pool about ¼ mile downstream, but there is no flow for several miles. The creek at this point drains 15.4 mi², but seldom

receives surface-water runoff. The streambed is mostly coarse gravel and boulders.

Dye was recovered between 23 and 28 days later, 16.2 miles to the northwest, at Bennett Spring. March, 1990 was a very wet month in the area, and high discharges at Bennett Spring caused by ground-water recharge quickly flushed dye from the system. Dye was detectable at Bennett Spring for only about four weeks. Though there were several heavy rains, little runoff reached the dye injection site. Dye recovery packets placed in the gaining reach of North Cobb Creek downstream of the injection site, at springs on the Osage Fork, and at several places in the Osage Fork, received no dye.

GOODWIN HOLLOW TRACES, DT 9 AND DT 10

Goodwin Hollow is a major losing stream draining a 72.1-mi² area east of the Niangua River in north-central Laclede County. It heads about 5 miles south of Lebanon, and intersects Dry Auglaize Creek, another losing stream, about 2 miles from the Camden County line in northern Laclede County. There are places in the upper watershed where pools can be found in the channel, but it is considered a losing stream throughout its length.

In the late 1960s, Bennett Spring experienced a gradual increase in nitrate and phosphate content. A study by Dean et al. (1969) concluded it was due, in part, to municipal wastewater released into Goodwin Hollow at Lebanon. A dye trace was conducted to substantiate this, and dye injected into Goodwin Hollow downstream of the wastewater treatment plant outfall reportedly was recovered at Bennett Spring. However, many of the details concerning the trace have been lost, so the trace was repeated during the present study to verify the earlier results. Since the original dye trace, Lebanon has constructed a new wastewater

treatment plant, which discharges into Dry Auglaize Creek.

On April 19, 1990, six pounds of Uranine C fluorescent dye was introduced into flow in Goodwin Hollow about 1.5 miles downstream of Missouri Highway 64, just northwest of Lebanon. The dye was injected into a flow of about 10 gpm that was disappearing at a gravel-bottomed pool; there was no flow downstream for at least ¼ mile. Upstream from the dye injection site, Goodwin Hollow drains 36.5 mi².

Dye was recovered at Bennett Spring, 9.1 miles to the west, 14 to 25 days later. Dye was also recovered during this same interval at Sweet Blue Spring 11.7 miles northwest of the injection site. Dye from Goodwin Hollow was detectable at Bennett Spring until about July 19. However, at Sweet Blue Spring, dye was not detected after May 23. Also, dye concentrations in packets from Bennett Spring were considerably higher than those at Sweet Blue Spring.

BRUSH CREEK TRIBUTARY TRACE, DT 11

Brush Creek is a northern tributary of the Osage Fork in southwestern Laclede County. The stream drains 42.2 mi². From the mouth to just upstream of Route PP, Brush Creek is perennial and considered a gaining stream. In the upper part of the

watershed, where Jefferson City Dolomite forms the bedrock surface, there are some short gaining reaches. Throughout most of its length, however, Brush Creek and its tributaries are typically dry and lose flow into the subsurface. Primarily, the

REFERENCE NUMBER	INJECTION SITE NAME	COUNTY	LOCATION (Q-SEC-TWN-RNG) (LONG(N)-LAT(W))	DYE TYPE AND AMOUNT	INJECTION DATE AND TIME	RECOVERY SITE NAME	COUNTY	LOCATION (Q-SEC-TWN-RNG) (LONG(N)-LAT(W))	FIRST RECOVERY INTERVAL FROM-TO
DT 1	UPPER FOURMILE CREEK	DALLAS	SW S 04 T33N R18W 37.26.13-92.55.07	URANINE C 6 POUNDS	JUN 27, 1989 1300 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	JUL 11, 1989 JUL 19, 1989
DT 2	JONES CREEK	DALLAS	SE S 03 T32N R16W 37.31.01-92.53.47	FLUORESCCEIN 1 POUND	AUG 30, 1989 1400 HRS	JOHNSON/WILKERSON SPRING	DALLAS	SE S 02 T32N R19W 37.31.00-92.58.51	SEP 5, 1989 OCT 4, 1989
DT 3*	CAVE CREEK	DALLAS	NE S 14 T34N R18W 37.40.00-92.52.02	RHODAMINE WT 3.5 LITERS	SEP 6, 1989 1000 HRS	SAND SPRING	DALLAS	SE S 25 T35N R18W 37.44.10-92.51.41	OCT 4, 1989 OCT 10, 1989
DT 4*	CAVE CREEK	DALLAS	NE S 14 T34N R18W 37.40.00-92.52.02	RHODAMINE WT 3.5 LITERS	SEP 6, 1989 1000 HRS	FAMOUS BLUE SPRING	DALLAS	NW S 36 T35N R18W 37.43.55-92.52.13	SEP 6, 1989 NOV 20, 1989
DT 5*	EAST FORK NIANGUA RIVER	WEBSTER	NW S 03 T31N R18W 37.26.23-92.54.15	RHODAMINE WT 3.5 LITERS	NOV 21, 1989 1500 HRS	NIANGUA RIVER AT ROUTE M	DALLAS	SE S 02 T32N R19W 37.31.00-92.59.02	NOV 30, 1989 DEC 5, 1989
DT 6*	EAST FORK NIANGUA RIVER	WEBSTER	NW S 03 T31N R18W 37.26.23-92.54.15	RHODAMINE WT 3.5 LITERS	NOV 21, 1989 1500 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	DEC 5, 1989 DEC 18, 1989
DT 7	STEINS CREEK	WRIGHT	NE S 28 T31N R15W 37.22.22-92.34.46	FLUORESCCEIN 15 POUNDS	JAN 11, 1990 1530 HRS	BIG SPRING	LACLEDE	NE S 06 T32N R15W 37.31.10-92.36.48	JAN 11, 1990 FEB 21, 1990
DT 8	NORTH COBB CREEK	LACLEDE	SE S 28 T34N R15W 37.37.42-92.35.00	RHODAMINE WT 3.5 LITERS	FEB 27, 1990 1400 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	MAR 22, 1990 MAR 27, 1990
DT 9*	GOODWIN HOLLOW	LACLEDE	NE S 04 T34N R16W 37.42.44-92.41.30	URANINE C 6 POUNDS	APR 19, 1990 1230 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	MAY 3, 1990 MAY 14, 1990
DT 10*	GOODWIN HOLLOW	LACLEDE	NE S 04 T34N R16W 37.42.44-92.41.30	URANINE C 6 POUNDS	APR 19, 1990 1230 HRS	SWEET BLUE SPRING	LACLEDE	NE S 30 T36N R17W 37.50.03-92.50.20	MAY 3, 1990 MAY 14, 1990
DT 11	BRUSH CREEK NEAR PHILLIPSBURG	LACLEDE	SE S 30 T33N R16W 37.32.40-92.43.48	RHODAMINE WT 1 LITER	JUN 1, 1990 1600 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	JUN 6, 1990 JUN 13, 1990
DT 12	UNNAMED TRIBUTARY OF OSAGE FORK	DALLAS	NW S 06 T32N R16W 37.31.04-92.37.50	RHODAMINE WT 500 ML	JUN 8, 1990 1215 HRS	RANDOLPH SPRING	LACLEDE	NE S 04 T32N R15W 37.31.14-92.37.01	JUN 8, 1990 JUN 12, 1990
DT 13	BEAR THICKET SINK	LACLEDE	SW S 28 T33N R16W 37.32.44-92.42.10	URANINE C 5 POUNDS	JUL 26, 1990 1445 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	AUG 6, 1990 AUG 7, 1990
DT 14	WEST FORK NIANGUA RIVER	WEBSTER	SE S 28 T31N R18W 37.22.31-92.55.03	RHODAMINE WT 200 ML	SEP 19, 1990 1630 HRS	VINEYARD SPRING	WEBSTER	NW S 28 T31N R18W 37.22.44-92.55.19	SEP 19, 1990 SEP 25, 1990
DT 15*	DRY FORK FOURMILE CREEK	DALLAS	NE S 28 T34N R18W 37.38.31-92.54.43	FLUORESCCEIN 2 POUNDS	OCT 5, 1990 1500 HRS	SAND SPRING	DALLAS	SE S 25 T35N R18W 37.44.10-92.51.48	OCT 17, 1990 OCT 24, 1990
DT 16*	DRY FORK FOURMILE CREEK	DALLAS	NE S 28 T34N R18W 37.38.31-92.54.43	FLUORESCCEIN 2 POUNDS	OCT 5, 1990 1500 HRS	FAMOUS BLUE SPRING	DALLAS	NW S 36 T35N R18W 37.43.55-92.52.13	SEP 25, 1990 OCT 24, 1990
DT 17	DOUSINBURY CREEK	LACLEDE	SE S 18 T33N R17W 37.34.25-92.50.05	RHODAMINE WT 2 LITERS	OCT 10, 1990 1610 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	NOV 15, 1990 NOV 28, 1990
DT 18	SPRING HOLLOW	LACLEDE	SE S 27 T34N R17W 37.38.04-92.47.06	FLUORESCCEIN 1 POUND	DEC 5, 1990 1500 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	DEC 17, 1990 DEC 19, 1990
V&E, 1987	UNNAMED TRIBUTARY OF SPRING HOLLOW	LACLEDE	NW S 23 T34N R17W 37.39.07-92.46.31	FLUORESCCEIN 5 POUNDS	JUL 1, 1987 1445 HRS	BENNETT SPRING	DALLAS	NW S 01 T34N R18W 37.43.00-92.51.24	JUL 9, 1987 JUL 14, 1987
M&V, 1980	DRY AUGLAIZE SINK	LACLEDE	NE S 24 T36N R16W 37.50.55-92.38.30	RHODAMINE WT 12 LITERS	APR 18, 1980 1000 HRS	HAHATONKA SPRING	CAMDEN	SW S 02 T37N R17W 37.58.26-92.46.01	APR 25, 1980 MAY 2, 1980
M, 1978	LOWER BEAR CREEK	LACLEDE	SW S 07 T35N R14W 37.46.26-92.30.29	RHODAMINE WT ---	APR 26, 1978 ---	CLIFF SPRING	LACLEDE	NW S 09 T35N R14W 37.47.06-92.28.33	APR 20, 1978 APR 22, 1978
S&M, 1976*	DRY AUGLAIZE CREEK	LACLEDE	NE S 30 T35N R15W 37.44.36-92.37.27	RHODAMINE WT ---	NOV 3, 1976 ---	SWEET BLUE SPRING	LACLEDE	NE S 30 T36N R17W 37.50.03-92.50.20	NOV 26, 1976 DEC 5, 1976
S&M, 1976*	DRY AUGLAIZE CREEK	LACLEDE	NE S 30 T35N R15W 37.44.36-92.37.27	RHODAMINE WT ---	NOV 3, 1976 ---	HAHATONKA SPRING	CAMDEN	SE S 02 T37N R17W 37.58.26-92.46.01	DEC 18, 1976 DEC 26, 1976

* INDICATES DYE WAS RECOVERED AT MORE THAN ONE SITE

--- INDICATES DATA IS MISSING OR IS INADEQUATE FOR CALCULATIONS

Table 22: Injection and recovery data for dye traces in the Bennett Spring area.

REFERENCE NUMBER	INJECTION SITE NAME	INJECTION ELEVATION (FT-MSL)	RECOVERY SITE NAME	RECOVERY ELEVATION (FT-MSL)	STRAIGHT LINE DISTANCE (MILES)	TRAVEL TIME		SLOPE (FT/MI)	VELOCITY	
						MIN	MAX		MIN	MAX
						(DAYS)			(MI/DAY)	
DT 1	UPPER FOURMILE CREEK	1105	BENNETT SPRING	870	8.5	14	22	27.6	0.39	0.61
DT 2	JONES CREEK	1175	JOHNSON/WILKERSON SPRING	1080	4.6	5	34	20.7	0.13	0.77
DT 3*	CAVE CREEK	990	SAND SPRING	845	4.7	28	34	30.9	0.14	0.17
DT 4*	CAVE CREEK	990	FAMOUS BLUE SPRING	850	4.6	---	75	30.4	0.06	---
DT 5*	EAST FORK NIANGUA RIVER	1145	NIANGUA RIVER AT ROUTE M	1065	7.0	9	14	11.5	0.50	0.78
DT 6*	EAST FORK NIANGUA RIVER	1145	BENNETT SPRING	870	19.3	14	27	14.3	0.71	1.38
DT 7	STEINS CREEK	1345	BIG SPRING	1050	10.3	---	41	28.6	0.25	---
DT 8	NORTH COBB CREEK	1107	BENNETT SPRING	870	16.2	23	28	14.6	0.58	0.70
DT 9*	GOODWIN HOLLOW	1127	BENNETT SPRING	870	9.1	14	25	28.2	0.36	.65
DT 10*	GOODWIN HOLLOW	1127	SWEET BLUE SPRING	770	11.7	14	25	30.5	0.47	0.84
DT 11	BRUSH CREEK TRIBUTARY	1205	BENNETT SPRING	870	13.8	5	12	24.3	1.15	2.76
DT 12	OSAGE FORK STATE FOREST	1115	RANDOLPH SPRING	1055	0.8	---	4	75.0	0.20	---
DT 13	BEAR THICKET SINK	1140	BENNETT SPRING	870	14.7	11	12	18.4	1.22	1.33
DT 14	WEST FORK NIANGUA RIVER	1265	VINEYARD SPRING	1260	0.34	---	6	14.7	0.06	---
DT 15*	DRY FORK FOURMILE CREEK	1050	SAND SPRING	845	7.1	12	19	29.1	0.37	0.59
DT 16*	DRY FORK FOURMILE CREEK	1050	FAMOUS BLUE SPRING	850	6.8	---	19	29.4	0.36	---
DT 17	DOUSINS CREEK	1240	BENNETT SPRING	870	10.0	35	49	37.0	0.20	0.29
DT 18	SPRING HOLLOW	1120	BENNETT SPRING	870	6.9	12	14	36.2	0.49	0.58
V&E, 1987	SPRING HOLLOW TRIBUTARY	1170	BENNETT SPRING	870	6.3	8	13	47.6	0.48	0.79
M&V, 1980	DRY AUGLAIZE SINK	970	HAHATONKA SPRING	670	11.0	7	14	27.3	0.79	1.57
M, 1978	LOWER BEAR CREEK	945	CLIFF SPRING	850	1.9	---	2	63.3	0.95	---
S&M, 1976*	DRY AUGLAIZE CREEK	1095	SWEET BLUE SPRING	770	13.4	23	32	24.3	0.42	0.58
S&M, 1976*	DRY AUGLAIZE CREEK	1095	HAHATONKA SPRING	670	17.6	45	53	24.1	0.33	0.39

* INDICATES DYE WAS RECOVERED AT MORE THAN ONE SITE --- INDICATES DATA IS MISSING OR IS INADEQUATE FOR CALCULATIONS

Table 23: Elevation, distance, travel time, and velocity data for dye traces in the Bennett Spring area.

The Hydrogeology of the Bennett Spring Area

losing zones are directly underlain by Roubidoux Formation. The losing portion of Brush Creek watershed, including Selva Hollow, has an area of about 27.9 mi².

On June 1, 1990, approximately one liter of Rhodamine WT (20%) dye was introduced into flow disappearing into the bed of a small Brush Creek tributary about 3 miles east of Phillipsburg, Missouri. Upstream from the dye injection point, the unnamed tributary drains 0.27 mi². The dye was injected where a flow of about 20 gpm was disappearing into a small depression in the streambed along the county road right-of-way; it was

carried underground within minutes after injection. There was no flow in the tributary downstream for about one-quarter mile to where it enters Brush Creek, but because of recent heavy rainfall, Brush Creek was carrying flow through this reach.

A relatively small amount of dye was used to determine if it would reappear in Brush Creek. Surprisingly, though only a small amount of dye was used it was detected at Bennett Spring between five and 14 days after injection, 13.8 miles to the north. Dye was not detected in Brush Creek, or at springs along the Osage Fork.

OSAGE FORK STATE FOREST TRACE, DT 12

Osage Fork State Forest is a small Missouri Department of Conservation forest west of the Osage Fork and south of Brush Creek, in southern Laclede County. A small, unnamed Osage Fork tributary flows through the parcel, and enters the Osage Fork about 1,000 feet downstream of Randolph Spring. The creek is typically dry throughout most of its reach, but small springs at the western edge of the state forest boundary provide flow for

a short distance before the water is lost underground.

On June 8, 1990, 500 ml of Rhodamine WT (20%) was injected into water disappearing into the streambed. The dye reappeared within four days at Randolph Spring, 0.8 miles to the east. Dye concentration at Randolph Spring was quite high, but no dye was recovered at Big Spring, a short distance upstream.

BEAR THICKET SINK TRACE, DT 13

Bear Thicket sink lies near a county road only a few hundred feet east of the Bear Thicket Church, about 5 miles east of Phillipsburg. The sinkhole is not shown on the Brush Creek 7.5 minute quadrangle, probably because it is fairly shallow and well hidden in trees and brush. The sinkhole is only a few feet above Brush Creek floodplain, and receives runoff from a 300-acre drainage. On the topographic map, an ephemeral watershed just north of the sinkhole is shown draining into a small pond, and then into Brush Creek. In reality, flow never reaches the pond; water flowing to the east in the small creek reverses direction upon reaching the pond dam, and flows west into the sinkhole.

Jefferson City Dolomite underlies the uplands in this area, and there are numerous small seeps

along the hillsides and several dug wells with shallow water levels. However, the valley bottoms are Roubidoux Formation, and flow from upland areas loses into the subsurface once it reaches the valleys. Brush Creek channel is only one-quarter mile southeast of the sinkhole, and through this reach Brush Creek is a losing stream.

In the early morning hours on July 26, 1990, thunderstorms dropped as much as 4 inches of precipitation in the area. At about 1445 hours, five pounds of Uranine C fluorescent dye was placed in flow disappearing through the base of the sinkhole. Prior to the rain, there were no discernible openings in the bottom of the sinkhole. When the dye was injected, a 1.5 foot by 2.5 foot hole had developed in soil materials in its base. Dye was almost instantly carried into the subsurface by the

2 ft³/sec flow entering the sinkhole throat. Peak inflow into the sinkhole, based on high-water marks at a road crossing upstream, was an estimated 50 ft³/sec.

This dye injection site is only 1.5 miles west of the Brush Creek tributary dye trace site, which had a very fast travel time to Bennett Spring. To gather

more accurate time-of-travel data, dye recovery packets were changed daily at Bennett Spring. Dye began to emerge between 10 and 11 days after injection, at Bennett Spring, which is 14.7 miles north of Bear Thicket sink; straight-line velocity was between 1.22 and 1.33 miles per day. Dye from the trace was detectable at Bennett Spring until late September, 1990.

WEST FORK NIANGUA RIVER TRACE, DT 14

West Fork of the Niangua River, with a drainage area of 27.9 mi², is a gaining stream throughout much of its length, but contains two notable water-loss zones. In the uppermost watershed, upstream from Marshfield's wastewater treatment plant, the stream carries flow much of the time, even during dry weather. The first water-loss zone is approximately 1 mile downstream of the wastewater treatment plant and 900 feet upstream from Vineyard Road. Here, during dry weather, the entire flow of West Fork is channelled underground. Almost all of the flow at this point is treated wastewater. The channel remains dry for about 1,700 feet to Vineyard Spring. Vineyard Spring has several outlets, including a solution-enlarged bedding plane opening in Jefferson City Dolomite about 6 feet above and 20 feet west of the West Fork channel, and several locations where groundwater rises through alluvial gravel closer to the channel. Flow from Vineyard Spring was not measured during this study, and the spring was previously unreported, but its average discharge is probably about 0.5 ft³/sec.

Except during very dry weather, flow appears to be continuous between Vineyard Spring and the East Fork confluence. However, during extended dry periods, flow in West Fork Niangua River disappears into the subsurface somewhere in its lower 4-mile reach.

On September 19, 1990, a dye trace was conducted to determine the outflow point or points of water lost into the subsurface upstream from Vineyard Road. Upstream from this point, West Fork drains 4.4 mi², but water disappearing here consists almost entirely of treated wastewater. Temperature and specific conductivity measurements of treated wastewater upstream from the

water-loss zone and of water from Vineyard Spring strongly indicated a hydrologic connection between the spring and the water-loss zone. Temperature and conductivity in West Fork just upstream of the loss zone were 64°F and 790 umho/cm. Vineyard Spring temperature and conductivity, 64°F and 740 umho/cm, were both much higher than normal for springs in this area. Because of the probable hydrologic connection, and to avoid unnecessary discoloration of the spring and stream, only 200 ml of Rhodamine Wt (20%) dye was used. The dye was recovered at Vineyard Spring during the first sampling period, less than six days after injection.

There was no flow at the East Fork-West Fork confluence when the dye was injected, but more than 2 inches of precipitation on September 21 and 22 created enough surface-water runoff to cause flow throughout the entire reach of West Fork. Consequently, dye was also recovered during the first sampling interval from dye recovery packets in the Niangua River at Gourley Ford, just upstream from Jake George Springs, and upstream from Route M bridge, undoubtedly due to dye transported by surface flow. Between October 3 and October 12, 1990, 14 to 23 days after dye injection, spectrofluorograms of dye recovery packets placed in three rises of Jake George Springs showed a fluorescence-curve deflection in the Rhodamine WT wavelength range. Such curve deflections are commonly seen after a Rhodamine WT dye trace when nearly all of the dye has been flushed from the spring system. Enough dye is present to cause a flattening of the curve in the Rhodamine WT wavelength range, but insufficient to create a peak. This occurred during only one sampling interval, and alone, is not sufficient evidence to conclude a hydro-

logic connection between water-loss zones on West Fork Niangua River and Jake George Springs. However, when the results of the East Fork Niangua River dye trace are also considered, it is likely that Jake George Springs receives recharge from the West Fork of the Niangua River.

When this dye trace began, plans called for a second dye injection in the downstream water-loss zone on West Fork after results from the first injection were known. Unfortunately, frequent rainfalls caused continuous flow through the lower reaches of West Fork throughout the remainder of the study.

DRY FORK FOURMILE CREEK TRACES, DT 15 AND DT 16

Dry Fork, with 6.5 mi² of drainage, is a major eastern tributary of Fourmile Creek. It drains much of the area south and west of Cave Creek watershed in eastern Dallas County. Dry Fork is a losing stream throughout most of its reach. Jefferson City Dolomite underlies the uplands in the southern part of the watershed, but the valley is developed in Roubidoux Formation. The stream contains a short gaining reach upstream of Route P where several small springs provide flow for a few hundred yards. In dry weather, though, flow disappears into the subsurface before reaching Route P.

On October 5, 1990, two pounds of fluorescein dye were injected into Dry Fork about 800 feet upstream from Route P. Upstream from here, Dry Fork drains 5.6 mi². Flow at the injection site was 5 to 10 gallons per minute, and it disappeared into the streambed at a small pool. The dye was recovered at Sand Spring, 7.1 miles to the northeast, between 12 and 19 days after injection. It was also recovered at Famous Blue Spring, 6.8 miles to the northeast, during the same interval. As with the Cave Creek dye trace, dye from Dry Fork passed beneath the Niangua River to emerge at Sand Spring and Famous Blue Spring.

DOUSINBURY CREEK TRACE, DT 17

Dousinbury Creek, an eastern tributary of the Niangua River, drains a 41.8 mi² area in southeastern Dallas and southwestern Laclede counties. Jefferson City Dolomite forms the bedrock surface throughout much of the upland portion of the watershed, but the creek valley is mostly developed in Roubidoux Formation. In its lower reach, from about 1.5 miles upstream of Route B crossing to the Niangua River, it is a gaining stream. Farther upstream, though, Dousinbury Creek is a losing stream. In its losing reach, Dousinbury Creek drains about 15.3 mi², including a section of Interstate-44 and the town of Phillipsburg.

On October 10, 1990, two liters of Rhodamine WT (20%) dye was introduced into Dousinbury Creek about 3 miles northwest of Phillipsburg. About 5.5 inches of precipitation occurring the previous week generated flow throughout some of upper Dousinbury Creek. Flow was receding

when dye was injected, but about 50 to 100 gpm was disappearing into the subsurface above the dye injection site. There was no flow downstream for several miles.

Dye was recovered at Bennett Spring, 10.0 miles to the north, between November 15 and 28, 35 to 49 days after dye was injected. This unusually long travel time may have been due to injection site flow conditions. Flow was receding at the injection site when dye was injected. The site was visited two days later, and the terminal loss point had migrated several hundred feet upstream from where dye had been placed. There was no significant precipitation after dye was injected until November 4, when about 0.6 inches of precipitation occurred. It is possible the dye was retained in the alluvial materials until later runoff flushed it into the groundwater system.

SPRING HOLLOW TRACE, DT 18

As previously mentioned, Bennett Spring rises in lower Spring Hollow. From the spring to the Niangua River, generally referred to as Bennett Spring Branch, flow is perennial. Much of the time, Bennett Spring discharge greatly exceeds flow in the Niangua River upstream from the spring branch.

Upstream from Bennett Spring the drainage is called Spring Hollow, and except for relatively brief periods after heavy precipitation, there is no flow. A few local exceptions occur, where small springs along Spring Hollow or its tributaries provide some inflow. Except for very short reaches, Spring Hollow upstream from Bennett Spring, with 42.5 mi² of drainage, is a losing stream.

One short, gaining reach in Spring Hollow is immediately upstream of Highway 32. Here, small springs provide perennial flow for about ½

mile upstream of the highway. The channel contains watercress throughout this reach, but flow generally disappears into the subsurface at or just downstream of the Highway 32 crossing. Upstream from here Spring Hollow drains 13.4 mi².

On December 5, 1990, one pound of fluorescein dye was injected into Spring Hollow about 1,200 feet downstream from Highway 32. Runoff from recent rains had extended flow downstream from where it normally disappears. The dye reappeared at Bennett Spring, 6.9 miles to the northwest, between 12 and 14 days after injection. Dye recovery packets at Bennett Spring were being changed approximately daily to obtain better travel time information. Based on the straight line distance, the groundwater velocity between the injection site and Bennett Spring was from 0.49 to 0.58 miles per day.

SPRING HOLLOW TRIBUTARY TRACE, V & E, 1987

A few Spring Hollow tributaries contain small springs whose flows may or may not reach Spring Hollow before losing into the subsurface. One of these is an eastern tributary of Spring Hollow about 1.5 miles downstream of Highway 32. Here, small springs flowing into a pond keep it full in dry weather; the overflow loses into the streambed a few hundred feet downstream.

On July 1, 1987, Jim Vandike and Cynthia Endicott, Division of Geology and Land Survey, and Diane Tucker, Bennett Spring State Park naturalist, injected 5 pounds of fluorescein into the outfall from the pond. The flow, about 5 gpm, carried dye into the subsurface a short distance downstream. The dye was recovered between eight and 13 days later, 6.3 miles to the northwest, at Bennett Spring.

DRY AUGLAIZE SINK TRACE, M & V, 1980

About 1.5 miles upstream from the mouth of Goodwin Hollow, and 1,500 feet north of Dry Auglaize Creek, is a large sinkhole developed along a county road. The sinkhole is about 30 feet deep, 200 feet in diameter, and drains about 90 acres. The proximity of the sinkhole to the road has made it an easy dumping site for unwanted trash and debris.

On April 18, 1980, following heavy rainfall, Don Miller and Jim Vandike, Division of Geology and Land Survey, injected about 12 liters of Rhodamine WT (20%) dye into runoff entering the sinkhole (photo 14). The dye was recovered 11 miles to the northwest, seven to 14 days after injection, at Hahatonka Spring.



Photo 14. *Injecting Rhodamine WT dye into a sinkhole near Dry Auglaize Creek. Dye from this trace was recovered at Hahatonka Spring, about 11 miles northeast of the sinkhole.*

LOWER BEAR CREEK TRACE, M, 1978

Bear Creek drains a 43.7 mi² area along Interstate 44 between Lebanon and the Gasconade River, and contains several gaining and losing reaches. The middle section of Bear Creek, a 4-mile reach roughly paralleling Interstate 44, is a gaining stream. About 1.5 miles downstream of the Interstate 44 crossing, flow disappears into the subsurface in dry weather, and the channel is dry for the next several miles downstream.

On April 20, 1978, Don Miller, Division of Geology and Land Survey, injected approximately 10 liters of Rhodamine WT dye into Bear Creek just upstream of the water-loss zone. Dye was recovered at Cliff Spring, 1.9 miles to the east, within two days after injection.

DRY AUGLAIZE CREEK TRACES, S & M, 1976

Dry Auglaize Creek is a major losing stream draining much of north-central Laclede County. Its drainage area, including Goodwin Hollow, is 205.8 mi², and it is a losing stream essentially its entire length. One section of upper Dry Auglaize Creek does have perennial flow, a reach several miles long downstream of the Lebanon wastewater treatment plant. Outfall from the treatment plant provides enough water to maintain flow for a few miles, but there is measurable flow-loss along the reach. The flow typically disappears into the subsurface before reaching Route F.

On November 3, 1976, Don Miller, Division of Geology and Land Survey, and John Skelton, U.S. Geological Survey, injected approximately 20 liters of Rhodamine Wt (20%) dye into Dry Auglaize Creek upstream of where flow disappears. Dye was recovered between 23 and 32 days later, 13.4 miles to the northwest, at Sweet Blue Spring. Dye was also recovered at Hahatonka Spring, 17.6 miles to the northwest, 45 to 53 days after injection.

RECHARGE AREAS OF MAJOR SPRINGS IN THE BENNETT SPRING AREA

INTRODUCTION

The major springs in the study area are outflow points for groundwater recharge. Each spring has a geographic area that provides its recharge. The size of a spring recharge area is proportional to the volume of water that is discharged from the spring, and the rate of groundwater recharge. Springs that discharge small amounts of water, generally, have small recharge areas. Those with high discharges have larger recharge areas.

The maximum amount of recharge possible for an area is the volume of precipitation. However, evaporation and transpiration greatly reduce this volume. Average annual recharge can be more realistically estimated from average annual runoff

data collected at surface-water gaging stations on major streams. Stream discharge consists of three components: 1) Direct surface-water runoff after precipitation events; 2) general groundwater inflow occurring along the stream; 3) and groundwater inflow from springs. It cannot be assumed that average annual runoff, as measured from a single gaging station on a given watershed, includes all of the groundwater recharge that takes place in that watershed. If groundwater recharge takes place upstream from a gaging station, and the spring outlet is downstream, then runoff will be underestimated because a part of the groundwater bypassed the gaging station. Additionally, interbasin transfer of groundwater commonly oc-

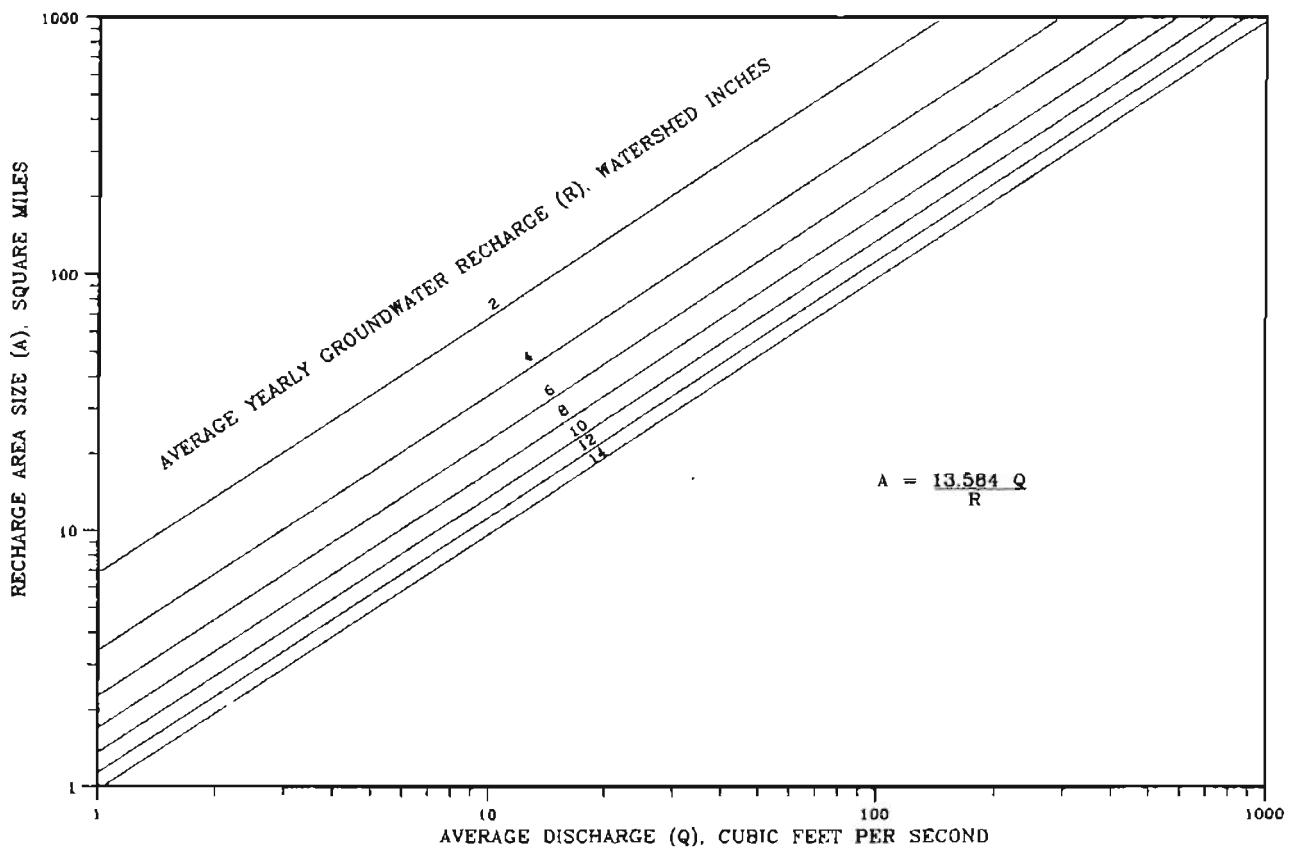


Figure 32: Average discharge versus recharge area size for various recharge rates.

curs in karst areas; groundwater recharge taking place in one surface-water drainage basin can emerge as spring flow in a different surface-water drainage basin. These factors can often be accounted for by examining long-term runoff data from several gaging stations in different watersheds in the region.

Long-term average annual runoff in the Bennett Spring area, based on stream-flow data ranges from about 11.5 inches in the northwestern portion, to 12.5 inches in the southeast (Gann and others, 1976). If all of the runoff became groundwater recharge, assuming an area average of 12 inches per year, then recharge in one square mile would provide an average flow of 0.88 ft³/sec to a spring. However, recharge rates vary spatially, and seldom does all of the runoff become groundwater recharge. Losing streams have finite recharge capacities and do not always channel all of the water entering them into the subsurface. Water-loss characteristics also vary between different losing streams. Some, like Spring Hollow and Goodwin Hollow, channel a high percentage of their runoff into the groundwater system. Others, like Fourmile Creek, Jones Creek, and West Fork Niangua River, have lower water-loss rates, and thus provide less recharge per unit area. Essentially 100 percent of the runoff generated within sinkhole watersheds becomes groundwater recharge, and there are many sinkholes in the Bennett Spring area, but the total area they drain is relatively small compared to the size of the study area. Figure 32 relates groundwater discharge to recharge-area size for various recharge rates. Dye tracing is likely the best and most accurate method for determining the recharge area for a spring; it establishes a physical connection between groundwater recharge and groundwater discharge. Unfortunately, a dye trace establishes the outflow point of water disappearing into the subsurface at a particular point and time. For a losing-stream dye trace, it is generally assumed that the drainage upstream of the dye injection site is within the recharge area of the spring where the dye reappears. This is true much of the time; upstream runoff can, potentially, reach the site where dye was injected. However, all of the recharge upstream of a particular dye injection site does not always recharge the same spring. For example, upper Fourmile Creek watershed

provides recharge to Bennett Spring. Lower Fourmile Creek watershed provides recharge to Famous Blue Spring and Sand Spring. Under certain flow conditions, when there is surface flow through the upstream losing reach, dye placed in upper Fourmile Creek may be recovered from all three springs. Obviously, the accuracy of recharge-area delineation increases with increased dye trace data, but seldom is it possible to conduct enough dye traces to identify a recharge area with total certainty.

Another technique for determining directions of groundwater movement is the use of potentiometric maps. A potentiometric map is a contour map showing the water-level elevations of wells penetrating a selected aquifer or aquifer zone. Direction of groundwater movement can be interpreted from potentiometric maps by constructing groundwater flow-lines perpendicular to the potentiometric contours; groundwater moves down-gradient and at right angles to the water-level contours. Potentiometric maps most accurately portray groundwater movement in aquifers under Darcian flow conditions, such as alluvial sand and gravel deposits, thick sandstones, and permeable glacial drift. Potentiometric maps of carbonate-rock aquifers where much flow is through solution-enlarged openings, may not accurately reflect groundwater-flow conditions. The problems are compounded where there are large areas with little or no water-level data. Miller (Harvey et al., 1983) constructed a potentiometric map which includes the Bennett Spring study area. Figure 33 was made from Miller's map, and shows water-surface elevations in wells primarily penetrating the Roubidoux Formation-Gasconade Dolomite aquifer sequence. Though groundwater-flow patterns interpreted from the potentiometric map do not, in all cases, agree with the dye tracing information, the potentiometric data is still useful in helping to delineate the recharge areas of the major springs.

Figure 34 shows recharge areas for the major springs in the Bennett Spring study area. Delineation of the recharge areas was based on dye tracing, potentiometric map data, stream-flow characteristics, and topography. The recharge-area boundaries shown in figure 34 should not be construed as absolute; they are simply the best estimation based on available information.

SUMMARIES OF INDIVIDUAL SPRING RECHARGE AREAS

BENNETT SPRING

Bennett Spring is the largest spring in the study area and has the largest recharge area, approximately 265 mi². Its known recharge area, based on dye tracing, includes Spring Hollow, upper Fourmile Creek, upper Dousinbury Creek, upper Brush Creek, and upper North Cobb Creek. It shares recharge with at least two other springs. Dye tracing shows recharge in East Fork Niangua River drainage is shared with Jake George Springs, and recharge in upper Goodwin Hollow is shared with Sweet Blue Spring, a total of about 70 mi² of shared recharge. Bennett Spring may also receive

recharge from upper Dry Auglaize Creek, upper Bear Creek, upper Cave Creek, a small part of upper Jones Creek watershed, and upper Danceyard Creek; further dye tracing will be needed to substantiate this.

About 213 mi² or 80.5 percent of Bennett Spring recharge area is in Laclede County. Dallas County contains about 22.5 mi² or 8.5 percent of its recharge area, and Webster County contains the remaining 29.5 mi², or 11 percent.

SAND SPRING AND FAMOUS BLUE SPRING

Dye traces show Sand Spring and Famous Blue Spring share a recharge area. Some springs share only a portion of their respective recharge areas, but Sand Spring and Famous Blue Spring likely share a single recharge area. This is supported by specific conductivity measurements of their discharge. Numerous conductivity measurements taken during different flow conditions showed essentially identical conductivity at the two springs. Conductivity values varied at both springs, of course; they were highest during low-flow condi-

tions and lowest during high-flow conditions, but with respect to each other conductivity varied little. Sand Spring and Famous Blue Spring are, apparently, separate outlets for the same spring system.

The recharge area for Sand Spring and Famous Blue Spring is likely all in Dallas County, and consists of about 33.5 mi², mostly in middle and lower Fourmile Creek watershed, and Cave Creek watershed.

JOHNSON-WILKERSON SPRING

During this study only one dye trace was made to Johnson-Wilkerson Spring. Jones Creek upstream from Route M is known to provide recharge. Two Jones Creek tributaries that are also losing streams, Goose Creek and Starvey Creek, likely provide recharge to the spring. The re-

charge area is thought to be about 19.6 mi². About 84 percent of it, 16.5 mi², lies in Dallas County. Most of the remainder is in Webster County. A small part of extreme southwestern Laclede County may provide a small amount of the spring recharge.

JAKE GEORGE SPRINGS

The recharge area for Jake George Springs, likely, is the Niangua River basin upstream from the springs. Dye from the East Fork Niangua River trace, which resurged between Gourley Ford and Route M, likely emerged at Jake George Springs. Temperature profiles and flow data for the Niangua River between

Route Y and Route M show Jake George Springs to be the only major groundwater outlets along that reach. The results of the West Fork Niangua River trace which indicate dye was received at Jake George Springs are, at best, tentative.

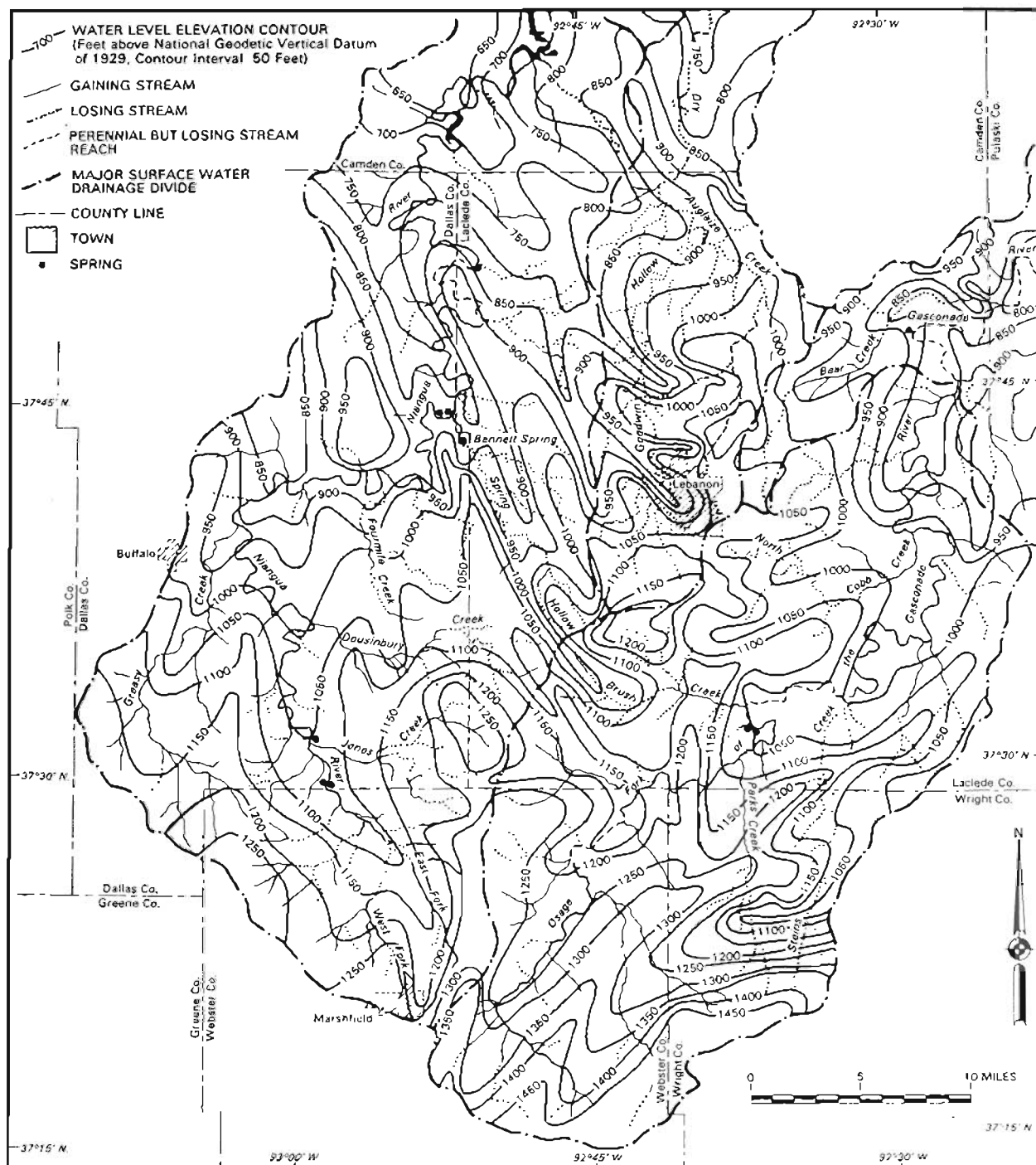
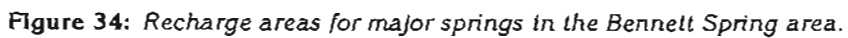


Figure 33: Potentiometric map of Roubidoux Formation-Gasconade Dolomite aquifer sequence in the Bennett Spring area (from Harvey et al., 1983).



Additional dye tracing will be necessary to better define the recharge area for Jake George Springs, but available data indicate recharge is provided by the East and West forks of the Niangua River, and is almost all from within Webster County. Recharge on the East Fork Niangua River is shared with Bennett Spring.

Additional losing streams in this area which likely provide recharge are Hollis Branch and Hagan Branch, on the east side of the Niangua, and Hawk Pond Branch and Givins Branch west of the river. Total recharge area size is estimated to be about 90 mi², with at least 26.5 mi² shared with Bennett Spring.

RANDOLPH SPRING

Randolph Spring likely has a relatively small recharge area. A dye trace shows a losing-stream watershed immediately west of the spring providing at least a part of the recharge. Recharge taking place farther west in

Churchill Hollow and Wildcat Hollow may also supply the spring. The recharge area likely contains about 4.7 mi², and is thought to be all west of the Osage Fork and south of Brush Creek within Laclede County.

BIG SPRING

A single dye trace shows Big Spring to receive recharge from upper Steins Creek, and additional dye tracing will be necessary to better define its recharge area. The recharge area likely includes much of Steins Creek watershed, and possibly

losing-stream drainage in upper Parks Creek watershed. Based on this, the recharge area may occupy some 70 mi². Though the spring rises in Laclede County, most of the recharge likely originates in northern Wright County.

CLIFF SPRING

Cliff Spring, one of the smaller springs discussed in this report, receives its recharge from Bear Creek watershed. However, there is far more water lost to the subsurface in Bear Creek watershed than can be accounted for at Cliff Spring. Bear Creek contains two gaining zones; a 2- to 3-mile reach upstream from its mouth, and a 3.5-mile reach 2 miles upstream from and 1.5 miles downstream from Interstate 44 near the middle of the watershed. Dye tracing has shown that flow lost into the subsurface from the upstream gaining reach recharges Cliff Spring, and thus the entire watershed upstream from the gaining reach could, under certain flow conditions, provide recharge. However, Bear Creek upstream from where dye was injected drains nearly 30 mi², enough area to supply a spring several times larger than Cliff Spring.

It is likely that Cliff Spring discharge is more dependent on flow lost into the subsurface in middle Bear Creek watershed than on recharge from the losing-stream reach in upper Bear Creek watershed. Obviously, since any surface-water runoff in upper Bear Creek watershed that reaches the downstream losing zone can provide recharge to Cliff Spring, the entire watershed upstream of the dye injection site is considered to be within the Cliff Spring recharge area. Based on this, the Cliff Spring recharge area contains about 30 mi². However, groundwater recharge occurring in the losing-stream zone in upper Bear Creek watershed may provide recharge to Bennett, Sweet Blue, or Hahatonka springs. Further dye tracing will be necessary to substantiate this.

SWEET BLUE SPRING

Two dye traces show Sweet Blue Spring to receive recharge from outside of the Niangua River basin; water lost from Dry Auglaize Creek and its tributary, Goodwin Hollow, provide recharge to Sweet Blue Spring. However, Sweet Blue Spring shares at least part of its recharge area with other springs. Upper Goodwin Hollow also provides recharge to Bennett Spring; upper Dry Auglaize Creek also recharges Hahatonka Spring. Several smaller losing-stream watersheds may

also provide recharge to Sweet Blue Spring. Mountain Creek, a Niangua River tributary south of Sweet Blue Spring, and Sweet Hollow, which drains the area immediately east of the spring, are both losing streams and may provide recharge to Sweet Blue Spring. The Sweet Blue Spring recharge area may be as large as about 117 mi². However, at least half, and possibly much more, of the recharge area is shared with Bennett and Hahatonka springs.

HAHATONKA SPRING

Hahatonka Spring is known to receive recharge from an area southeast of the spring in Dry Auglaize Creek watershed. As previously mentioned, it shares a part of its recharge area with Sweet Blue Spring. A dye trace from a sinkhole near the Goodwin Hollow confluence with Dry Auglaize Creek indicates Dry Auglaize Creek at and downstream from the dye injection site provides recharge only to Hahatonka Spring. As with Dry Auglaize Creek, there is likely a section of middle and lower Goodwin Hollow that recharges both Hahatonka and Sweet Blue springs.

Available information indicates Hahatonka Spring has a recharge area of about 122 mi². At least 20 mi², and potentially much more, is shared with Sweet Blue Spring. Goodwin Hollow and Dry Auglaize Creek provide much of the recharge, but smaller losing-stream drainages immediately south and east of the spring may also provide appreciable recharge. Additional dye tracing will be necessary to better delineate the Hahatonka Spring recharge area, and to more fully understand the mechanisms allowing multiple spring recharge in Goodwin Hollow and Dry Auglaize Creek watersheds.

HYDROLOGIC BUDGET FOR THE BENNETT SPRING RECHARGE AREA

Precipitation is the source of essentially all water in the study area. But after precipitation reaches the ground, it can be distributed a number of ways (fig. 35). Part of the water can enter the soil materials, be stored for a time, and return to the atmosphere as evaporation, or be transpired by plants. If soils are dry and the precipitation amount is low, most if not all of the water is ultimately evaporated or transpired. If the soil is saturated, or the amount of precipitation high, surface-water runoff and groundwater recharge

occurs. A hydrologic budget is an accounting procedure used to describe the distribution of water from precipitation. In essence, it is a mathematical procedure that allows losses due to evaporation and transpiration to be estimated, and thus determine the amount of water available for groundwater recharge and surface-water runoff.

There are several techniques used to estimate evaporation and transpiration. Most of them require data not ordinarily collected. A method

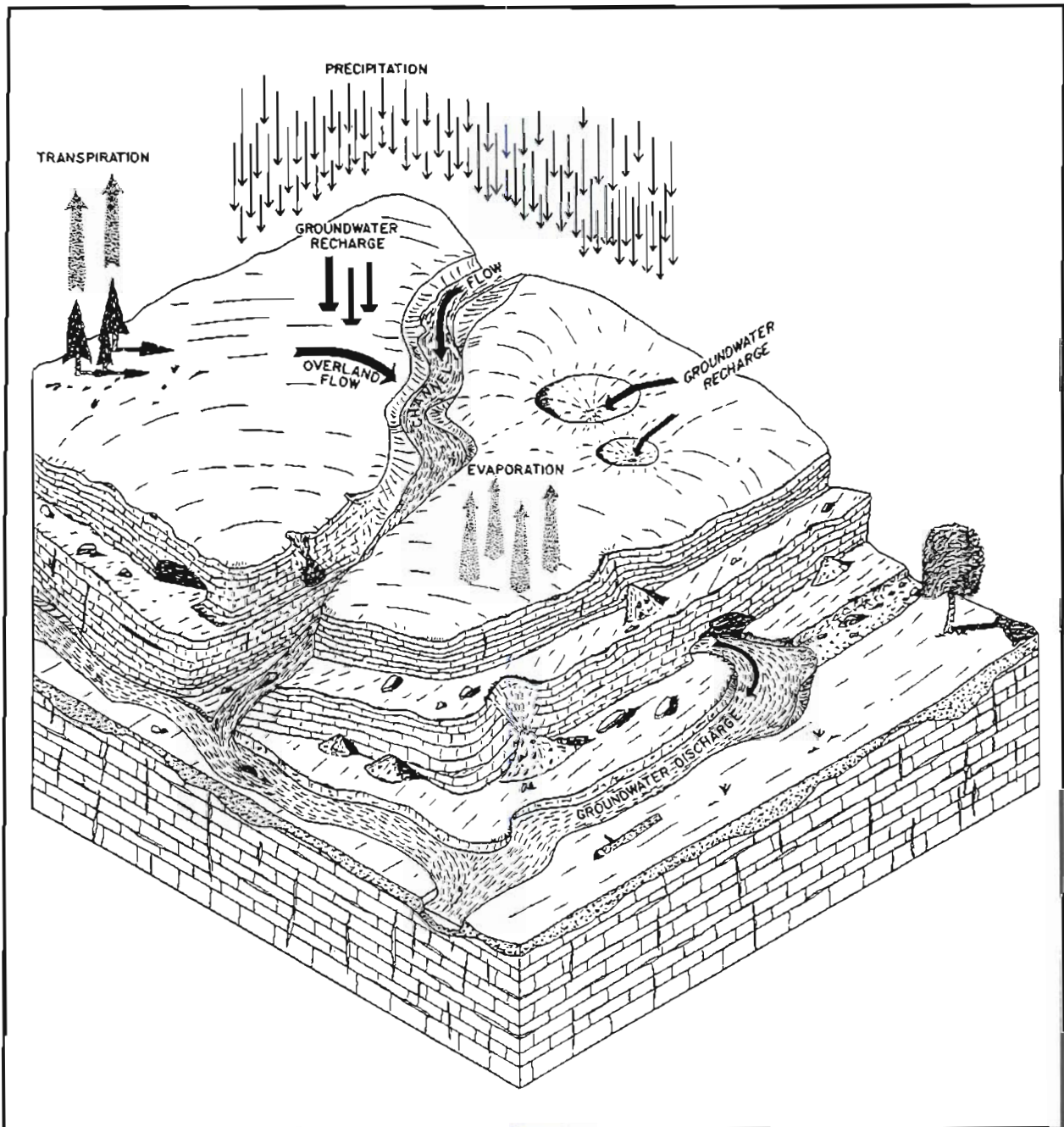


Figure 35: Conceptual drawing showing water distribution in a karst setting.

developed by Thornthwaite and Mather (1955 and 1957), commonly called the Thornthwaite Method, estimates evaporation and transpiration in combined form as evapotranspiration, and requires only temperature and precipitation data in calculating the hydrologic budget for an area.

The hydrologic budget of the Bennett Spring recharge area was calculated using a modified version of a Thornthwaite Method algorithm developed by Willmont (1978). With the Thornthwaite Method, potential evapotranspiration, the evapotranspiration that will occur if ample moisture is available, is calculated from average daily or monthly temperatures based on 12 hours of daylight per day. It is corrected for day length, based on latitude and date, to yield adjusted potential evapotranspiration. Actual evapotranspiration is calculated using potential evapotranspiration, by correcting for the amount of soil moisture available. It is assumed that the availability of soil moisture to evapotranspiration will decrease linearly with the ratio of actual to potential maximum soil moisture, so as soil moisture decreases, the amount of actual evapotranspiration also decreases. Surplus moisture, that which is available for surface-water runoff or groundwater recharge, occurs when the amount of soil moisture storage is at its maximum, or field capacity, and precipitation exceeds evapotranspiration. It is assumed that there is no surplus moisture unless soil moisture storage is at field capacity. Also, in the hydrologic budget, no distinction is made between surface-water runoff and groundwater recharge. Soil moisture deficit is the amount of evapotranspiration that could not occur due to lack of soil moisture.

Hydrologic budgets, regardless of data density and calculation methodology, are estimates of natural water distribution. No mathematical model can allow for the natural variations in soil materials, and seldom are temperature and rainfall data detailed enough to accurately account for temporal and spatial variations. Despite their limitations, hydrologic budgets are useful tools for estimating surface-water runoff and groundwater recharge characteristics in an area under a variety of climatic conditions.

Two hydrologic budgets were calculated for the Bennett Spring recharge area. The first, calculated monthly for a 35-year period beginning October, 1955, and ending September, 1990, was based on weighted average monthly precipitation at Lebanon and Marshfield, and average monthly temperature at Lebanon. Soil moisture storage field capacity is assumed to be 6 inches. A yearly summary of this long-term hydrologic budget is shown in table 24. Temperature throughout this 35-year period averaged 57.1°F., precipitation averaged 40.99 in./year, and estimated actual evapotranspiration averaged 27.1 in./year. Calculated surplus moisture averaged 13.92 in./year, which is about 2 inches greater than estimates based on surface-water gaging station data.

The second hydrologic budget was calculated daily for water year 1989-1990. Average daily temperature was determined for the recharge area using a polygon weighting technique applied to daily high and low temperatures from Marshfield, Buffalo 3S, and Lebanon 2W weather observation stations. Figure 36 shows daily high and low temperatures from Marshfield, Buffalo 3S, and Lebanon 2W, along with weighted daily temperature. Daily precipitation from the three U.S. Weather Service observation stations, Missouri Department of Conservation-Lebanon, plus the 10 precipitation stations established for this study, were averaged using a polygon weighting technique to obtain weighted precipitation for the recharge area. Table 25 and figure 37 show weighted daily precipitation, water year 1989-1990, for the Bennett Spring recharge area. A soil moisture storage field capacity of 6 inches was assumed.

The daily hydrologic budget for the Bennett Spring recharge area is shown in table 26. Weighted temperature for the water year was 57.6°F., and weighted precipitation was 48.52 inches. Actual evapotranspiration was calculated to be 25.71 inches, and surplus moisture was calculated to be 20.73 inches. Thus, about 20.7 watershed inches of moisture was available during water year 1989-1990 for surface-water runoff and groundwater recharge, which is considerably greater than the long-term calculated average of 13.9 inches per year.

Hydrologic Budget

HEAT INDEX I = 64.05452 INITIAL SOIL MOISTURE (INCHES) = 3 SOIL MOISTURE STORAGE FIELD CAPACITY (INCHES) = 6
AVERAGE LATITUDE OF AREA (DEGREES) = 37.55

TEMP = TEMPERATURE (F) PREC = PRECIPITATION (INCHES) POT ET = UNADJUSTED POTENTIAL EVAPOTRANSPIRATION (INCHES)
ADJ ET = ADJUSTED POTENTIAL EVAPOTRANSPIRATION (INCHES) P-ADJ ET = PRECIPITATION LESS ADJ. POT. EVAPOTRANSPIRATION (IN)

SMS = SOIL MOISTURE STORAGE (INCHES) ACT ET = ACTUAL EVAPOTRANSPIRATION (INCHES)
CHANGE SMS = CHANGE IN SOIL MOISTURE STORAGE FROM PREVIOUS YEAR (INCHES)

DEFICIT = AMOUNT OF EVAPOTRANSPIRATION THAT CANNOT TAKE PLACE DUE TO INADEQUATE SOIL MOISTURE (INCHES)
SURPLUS = AMOUNT OF WATER REMAINING ABOVE SOIL MOISTURE STORAGE FIELD CAPACITY THAT WAS NOT EVAPORATED OR TRANSPIRED (IN)

WATER YEAR	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1956	56.68	28.81	28.00	32.28	-3.47	1.50	28.34	-1.50	3.94	1.97
1957	57.02	47.02	27.93	31.89	15.13	1.55	27.62	0.05	4.26	19.34
1958	54.78	50.10	25.38	29.27	20.83	6.00	29.03	4.45	0.25	16.63
1959	56.76	33.69	27.87	31.89	1.80	2.24	28.01	-3.76	3.88	9.43
1960	55.15	32.47	26.17	30.15	2.32	0.82	23.22	-1.42	6.94	10.67
1961	55.52	45.22	25.55	29.17	16.05	3.28	24.62	2.45	4.54	18.14
1962	55.99	35.21	27.44	31.71	3.50	3.49	23.62	0.22	8.08	11.37
1963	56.79	31.36	28.77	33.02	-1.66	0.99	27.30	-2.51	5.72	6.56
1964	57.34	31.78	29.35	33.48	-1.70	1.41	27.27	0.42	6.21	4.08
1965	56.28	48.04	26.93	30.87	17.17	6.00	30.13	4.59	0.74	13.32
1966	56.24	36.04	26.91	30.78	5.26	4.42	26.50	-1.58	4.28	11.12
1967	56.12	38.79	25.72	29.35	9.44	3.64	27.95	-0.78	1.39	11.62
1968	55.48	47.61	26.13	30.12	17.49	2.30	28.11	-1.33	2.01	20.83
1969	55.58	42.41	26.70	30.93	11.48	2.06	27.03	-0.24	3.90	15.62
1970	55.59	42.32	27.23	31.47	10.85	6.00	26.30	3.94	5.16	12.08
1971	55.76	32.89	26.36	30.36	2.53	2.03	27.86	-3.97	2.49	9.00
1972	57.61	38.58	28.39	32.33	6.25	2.38	27.42	0.35	4.91	10.82
1973	55.32	52.20	26.28	30.40	21.80	1.05	25.02	-1.32	5.38	28.50
1974	56.96	47.33	27.38	31.27	16.06	3.54	29.37	2.49	1.90	15.47
1975	56.13	45.51	26.90	31.13	14.38	2.81	26.56	-0.73	4.57	19.67
1976	57.37	30.85	27.60	31.24	-0.39	0.90	25.07	-1.91	6.17	7.69
1977	55.64	40.90	28.46	33.07	7.83	3.76	31.09	2.85	1.98	6.96
1978	54.56	39.66	27.75	32.05	7.61	3.50	30.50	-0.26	1.56	9.42
1979	53.85	47.17	25.69	29.53	17.64	3.24	28.43	-0.25	1.11	19.00
1980	57.24	32.51	29.67	34.34	-1.83	0.58	25.94	-2.66	8.41	9.23
1981	56.55	43.01	27.18	31.24	11.77	2.46	29.26	1.88	1.98	11.87
1982	55.23	38.39	26.53	30.59	7.80	1.50	26.57	-0.97	4.02	12.79
1983	56.70	41.99	27.36	31.34	10.65	0.74	24.19	-0.75	7.15	18.55
1984	53.31	47.80	24.96	28.70	19.10	2.59	24.16	1.85	4.54	21.79
1985	55.61	52.68	27.12	31.05	21.63	1.23	26.43	-1.36	4.62	27.61
1986	56.93	50.22	28.62	32.91	17.31	6.00	28.39	4.77	4.52	17.06
1987	57.83	39.88	29.22	33.74	6.14	1.45	29.82	-4.55	3.92	14.60
1988	55.92	40.79	27.29	31.52	9.27	0.93	25.47	-0.52	6.05	15.84
1989	55.47	32.75	25.87	29.75	3.00	0.97	23.92	0.04	5.83	8.79
1990	57.59	48.52	28.99	32.89	15.63	1.65	28.09	0.68	4.80	19.75

WATER BALANCE AVERAGES FOR WATER YEARS 1956 TO 1990 - AVG. HEAT INDEX = 64.05452

56.08	40.99	27.25	31.31	9.68	1.65	27.10	-0.04	4.21	13.92
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Table 24: Hydrologic budget, water years 1956 through 1990, for the Bennett Spring recharge area.

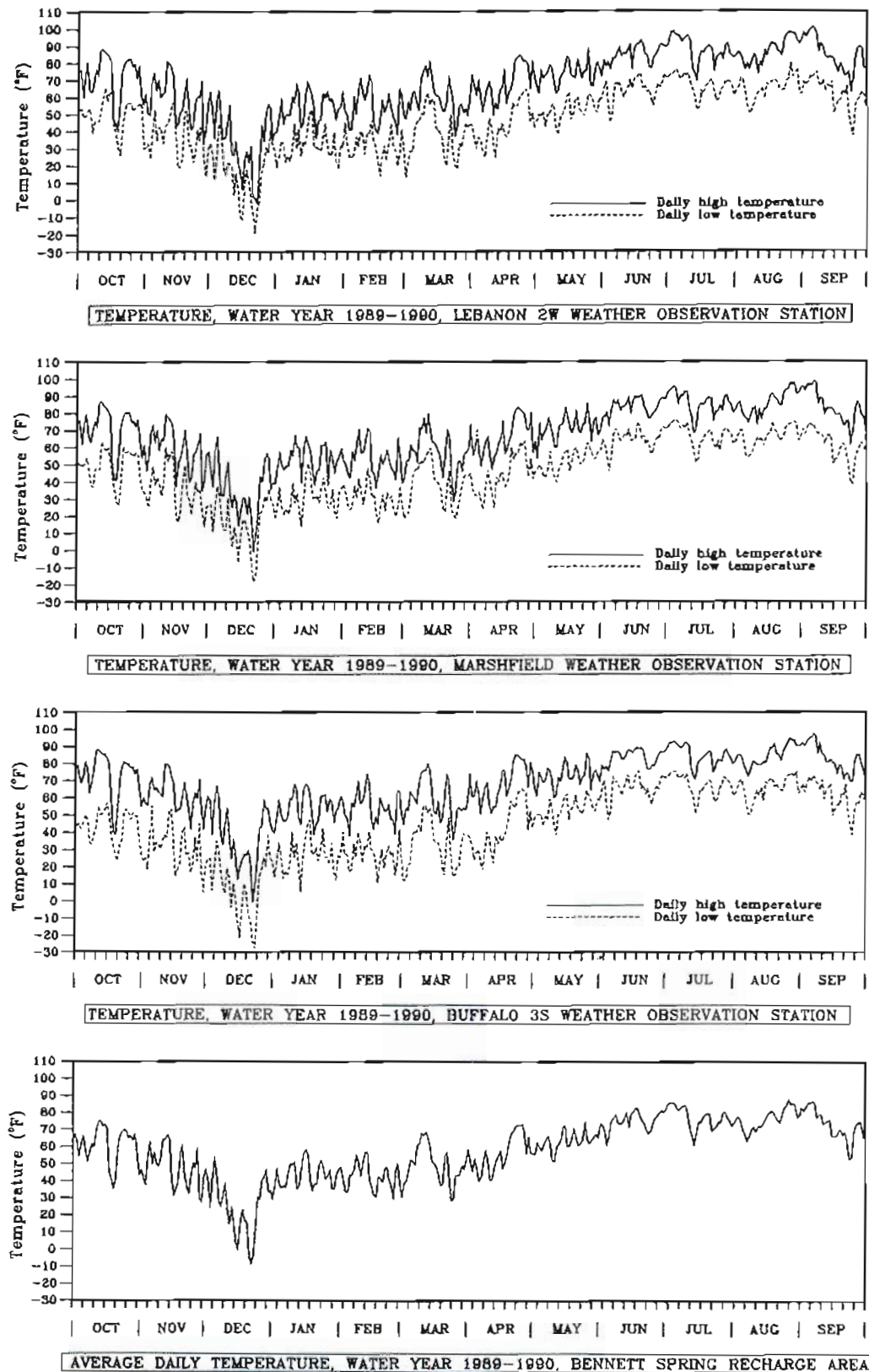


Figure 36: Water year 1989-1990 temperature data for the Bennett Spring area.

WEIGHTED PRECIPITATION, WATER YEAR 1989-1990, BENNETT SPRING AREA

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	....	....	....	....	0.44	0.14	0.01	0.10	0.07	....	....	....
2	....	....	....	0.01	0.39	....	....	0.13	0.02	....	....	....
3	....	....	....	0.30	0.14	....	....	1.04	....	....	0.89	....
4	....	....	....	0.07	0.39	....	....	0.55	....	....	0.87	....
5	....	....	0.15	....	0.03	0.09	0.19	0.03	....	0.09	0.24	....
6	0.26	....	....	....	0.10	0.16	0.16	0.02	0.07	0.13	....	0.08
7	0.97	0.03	....	....	0.01	0.51	....	....	....	0.01	....	0.03
8	....	....	0.09	....	0.03	0.22	....	....	0.03	....	....	0.08
9	....	....	0.04	....	0.28	....	0.14	0.05	0.46	....	....	....
10	....	....	....	....	....	0.09	1.24	0.02	0.01	....	....	0.13
11	....	....	....	....	....	0.17	0.03	0.12	....	1.15	0.03	0.26
12	....	....	....	....	....	0.38	....	0.79	....	0.78	0.23	0.21
13	....	0.14	....	....	0.02	0.25	0.37	0.05	....	0.82	0.20	0.04
14	....	2.16	....	....	0.29	1.31	0.27	0.18	0.41	0.03	....	0.07
15	....	0.53	0.11	0.01	1.28	1.13	0.08	0.50	0.20	0.02	0.21	....
16	0.08	0.03	....	0.40	0.17	....	0.07	0.96	....	....	0.31	....
17	0.04	....	0.01	1.33	....	....	0.31	0.22	....	....	0.07	0.03
18	....	....	....	0.09	....	0.07	0.01	0.04	....	....	....	0.59
19	....	....	....	0.96	....	0.08	....	0.40	0.16	....	0.13	0.23
20	....	0.02	....	0.63	....	....	0.16	0.10	0.34	....	0.10	0.02
21	....	0.04	....	....	0.32	....	0.04	0.88	0.09	0.30	....	0.54
22	....	0.14	....	....	0.30	0.04	....	....	0.37	0.28	....	0.16
23	....	....	....	....	0.09	0.10	....	....	0.07	0.02	....	....
24	....	....	....	0.03	....	0.32	....	0.04	....	0.01	....	....
25	....	....	0.06	0.12	....	0.13	....	0.21	0.26	0.09	....	....
26	....	....	....	....	0.01	0.09	....	3.39	0.13	1.37	....	....
27	....	....	....	....	0.06	0.03	0.55	0.39	0.02	0.51	....	....
28	....	....	0.01	....	0.23	0.46	0.25	0.04	....	....	....	....
29	....	....	0.30	....	....	0.08	....	0.01	....	....	....	0.01
30	0.27	....	....	....	....	0.22	0.02	0.02	....	....	....	0.03
31	0.02	....	....	0.06	....	0.03	....	0.15	....	....	....	....
MONTHLY TOTALS	0.74	3.09	0.77	4.01	4.57	6.10	3.90	11.23	2.71	5.61	3.28	2.51

TOTAL WEIGHTED PRECIPITATION: 48.52 INCHES

NUMBER OF DAYS WITH PRECIPITATION: 178

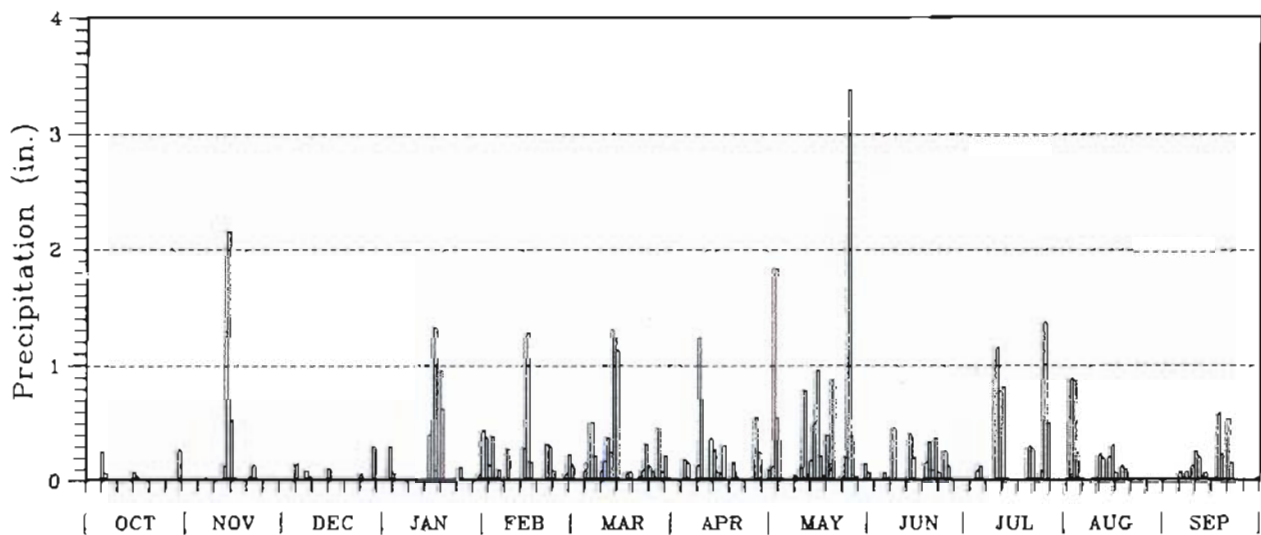


Table 25 and Figure 37: Weighted precipitation, water year 1989-1990, for the Bennett Spring recharge area.

DAILY HYDROLOGIC BUDGET FOR THE BENNETT SPRING AREA, WATER YEAR 1989-1990

HEAT INDEX I = 71.5877 INITIAL SOIL MOISTURE (INCHES) = .97 SOIL MOISTURE STORAGE FIELD CAPACITY (INCHES) = 6
AVERAGE LATITUDE OF AREA = 37.55

TEMP = TEMPERATURE (F) PREC = PRECIPITATION (INCHES) POT ET = UNADJUSTED POTENTIAL EVAPOTRANSPIRATION (INCHES)
ADJ ET = ADJUSTED POTENTIAL EVAPOTRANSPIRATION (INCHES) P-ADJ ET = PRECIPITATION LESS ADJ. POT. EVAPOTRANSPIRATION (INCHES)
SMS = SOIL MOISTURE STORAGE (INCHES) ACT ET = ACTUAL EVAPOTRANSPIRATION (INCHES)
CHANGE SMS = CHANGE IN SOIL MOISTURE STORAGE FROM PREVIOUS DAY (INCHES)
DEFICIT = AMOUNT OF EVAPOTRANSPIRATION THAT CANNOT TAKE PLACE DUE TO INADEQUATE SOIL MOISTURE (INCHES)
SURPLUS = AMOUNT OF WATER REMAINING ABOVE SOIL MOISTURE STORAGE FIELD CAPACITY THAT WAS NOT EVAPORATED OR TRANSPIRED (INCHES)

OCT - 1989

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	67.54	0.00	0.11	0.11	-0.11	0.95	0.02	-0.02	0.09	0.00
2	63.56	0.00	0.09	0.09	-0.09	0.94	0.01	-0.01	0.07	0.00
3	54.24	0.00	0.05	0.05	-0.05	0.93	0.01	-0.01	0.04	0.00
4	61.52	0.00	0.08	0.08	-0.08	0.92	0.01	-0.01	0.07	0.00
5	66.94	0.00	0.11	0.10	-0.10	0.90	0.02	-0.02	0.09	0.00
6	58.63	0.26	0.07	0.07	0.19	1.10	0.07	0.19	0.00	0.00
7	50.82	0.07	0.04	0.04	0.03	1.13	0.04	0.03	0.00	0.00
8	56.71	0.00	0.06	0.06	-0.06	1.12	0.01	-0.01	0.05	0.00
9	61.43	0.00	0.08	0.08	-0.08	1.10	0.01	-0.01	0.06	0.00
10	59.73	0.00	0.07	0.07	-0.07	1.09	0.01	-0.01	0.06	0.00
11	69.65	0.00	0.12	0.11	-0.11	1.07	0.02	-0.02	0.09	0.00
12	74.80	0.00	0.15	0.14	-0.14	1.05	0.02	-0.02	0.11	0.00
13	75.64	0.00	0.15	0.14	-0.14	1.02	0.03	-0.03	0.12	0.00
14	71.75	0.00	0.13	0.12	-0.12	1.00	0.02	-0.02	0.10	0.00
15	73.44	0.00	0.14	0.13	-0.13	0.98	0.02	-0.02	0.11	0.00
16	70.42	0.08	0.12	0.12	-0.04	0.97	0.09	-0.01	0.03	0.00
17	45.38	0.04	0.02	0.02	0.02	0.99	0.02	0.02	0.00	0.00
18	40.95	0.00	0.01	0.01	-0.01	0.99	0.00	0.00	0.01	0.00
19	34.82	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.00
20	41.40	0.00	0.01	0.01	-0.01	0.99	0.00	0.00	0.01	0.00
21	59.29	0.00	0.07	0.07	-0.07	0.98	0.01	-0.01	0.05	0.00
22	66.11	0.00	0.10	0.09	-0.09	0.96	0.02	-0.02	0.08	0.00
23	69.32	0.00	0.12	0.11	-0.11	0.94	0.02	-0.02	0.09	0.00
24	69.73	0.00	0.12	0.11	-0.11	0.93	0.02	-0.02	0.09	0.00
25	69.35	0.00	0.12	0.11	-0.11	0.91	0.02	-0.02	0.09	0.00
26	64.95	0.00	0.10	0.09	-0.09	0.90	0.01	-0.01	0.07	0.00
27	66.70	0.00	0.10	0.09	-0.09	0.88	0.01	-0.01	0.08	0.00
28	63.13	0.00	0.09	0.08	-0.08	0.87	0.01	-0.01	0.07	0.00
29	67.61	0.00	0.11	0.10	-0.10	0.86	0.01	-0.01	0.08	0.00
30	57.06	0.27	0.06	0.06	0.21	1.07	0.06	0.21	0.00	0.00
31	43.13	0.02	0.02	0.01	0.01	1.08	0.01	0.01	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR OCT - 1989 MONTHLY HEAT INDEX = 6.38

61.15 0.74 2.63 2.46 -1.72 1.08 0.63 0.11 1.83 0.00

NOV - 1989

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	46.92	0.00	0.03	0.02	-0.02	1.07	0.00	0.00	0.02	0.00
2	40.99	0.00	0.01	0.01	-0.01	1.07	0.00	0.00	0.01	0.00
3	37.32	0.00	0.00	0.00	0.00	1.07	0.00	0.00	0.00	0.00
4	54.40	0.00	0.05	0.05	-0.05	1.06	0.01	-0.01	0.04	0.00
5	63.64	0.00	0.09	0.08	-0.08	1.05	0.01	-0.01	0.07	0.00
6	49.09	0.00	0.03	0.03	-0.03	1.04	0.01	-0.01	0.02	0.00
7	56.73	0.03	0.06	0.05	-0.02	1.04	0.03	0.00	0.02	0.00
8	50.13	0.00	0.04	0.03	-0.03	1.03	0.01	-0.01	0.03	0.00
9	48.06	0.00	0.03	0.03	-0.03	1.03	0.00	0.00	0.02	0.00
10	53.50	0.00	0.05	0.04	-0.04	1.02	0.01	-0.01	0.03	0.00
11	64.27	0.00	0.09	0.08	-0.08	1.01	0.01	-0.01	0.07	0.00
12	63.91	0.00	0.09	0.08	-0.08	1.00	0.01	-0.01	0.07	0.00
13	67.29	0.14	0.11	0.09	0.05	1.04	0.09	0.05	0.00	0.00
14	64.63	2.16	0.09	0.08	2.08	3.12	0.08	2.08	0.00	0.00
15	42.53	0.53	0.02	0.01	0.52	3.64	0.01	0.52	0.00	0.00
16	31.00	0.03	0.00	0.00	0.03	3.67	0.00	0.03	0.00	0.00
17	35.37	0.00	0.00	0.00	0.00	3.67	0.00	0.00	0.00	0.00
18	39.56	0.00	0.01	0.01	-0.01	3.66	0.00	0.00	0.00	0.00
19	56.06	0.00	0.06	0.05	-0.05	3.63	0.03	-0.03	0.02	0.00
20	61.57	0.02	0.08	0.07	-0.05	3.60	0.05	-0.03	0.02	0.00
21	44.05	0.04	0.02	0.02	0.02	3.63	0.02	0.02	0.00	0.00
22	36.45	0.14	0.00	0.00	0.14	3.77	0.00	0.14	0.00	0.00
23	32.28	0.00	0.00	0.00	0.00	3.77	0.00	0.00	0.00	0.00
24	42.52	0.00	0.02	0.01	-0.01	3.76	0.01	-0.01	0.00	0.00
25	50.65	0.00	0.04	0.03	-0.03	3.74	0.02	-0.02	0.01	0.00
26	47.32	0.00	0.03	0.02	-0.02	3.72	0.01	-0.01	0.00	0.00
27	59.26	0.00	0.07	0.06	-0.06	3.69	0.04	-0.04	0.00	0.00
28	29.58	0.00	0.00	0.00	0.00	3.69	0.00	0.00	0.00	0.00
29	27.31	0.00	0.00	0.00	0.00	3.69	0.00	0.00	0.00	0.00
30	42.63	0.00	0.02	0.01	-0.01	3.68	0.01	-0.01	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR NOV - 1989 MONTHLY HEAT INDEX = 2.86

47.97 3.09 1.14 0.97 2.12 3.68 0.49 2.62 0.48 0.00

Table 26: Hydrologic budget, water year 1989-1990, Bennett Spring recharge area.

DEC - 1989

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	47.39	0.00	0.03	0.02	-0.02	3.66	0.01	-0.01	0.01	0.00
2	39.59	0.00	0.01	0.01	-0.01	3.66	0.00	0.00	0.00	0.00
3	23.92	0.00	0.00	0.00	0.00	3.66	0.00	0.00	0.00	0.00
4	42.40	0.00	0.01	0.01	-0.01	3.65	0.01	-0.01	0.00	0.00
5	54.51	0.15	0.05	0.04	0.11	3.76	0.04	0.11	0.00	0.00
6	42.33	0.00	0.01	0.01	-0.01	3.75	0.01	-0.01	0.00	0.00
7	27.66	0.00	0.00	0.00	0.00	3.75	0.00	0.00	0.00	0.00
8	24.86	0.09	0.00	0.00	0.09	3.84	0.00	0.09	0.00	0.00
9	32.83	0.04	0.00	0.00	0.04	3.88	0.00	0.04	0.00	0.00
10	38.83	0.00	0.01	0.01	-0.01	3.88	0.00	0.00	0.00	0.00
11	23.03	0.00	0.00	0.00	0.00	3.88	0.00	0.00	0.00	0.00
12	14.19	0.00	0.00	0.00	0.00	3.88	0.00	0.00	0.00	0.00
13	25.13	0.00	0.00	0.00	0.00	3.88	0.00	0.00	0.00	0.00
14	14.87	0.00	0.00	0.00	0.00	3.88	0.00	0.00	0.00	0.00
15	3.78	0.11	0.00	0.00	0.11	3.99	0.00	0.11	0.00	0.00
16	-0.36	0.00	0.00	0.00	0.00	3.99	0.00	0.00	0.00	0.00
17	16.48	0.01	0.00	0.00	0.01	4.00	0.00	0.01	0.00	0.00
18	23.44	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
19	16.39	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
20	16.35	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
21	-1.65	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
22	-9.20	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
23	-3.25	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
24	11.42	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
25	30.76	0.06	0.00	0.00	0.06	4.06	0.00	0.06	0.00	0.00
26	28.62	0.00	0.00	0.00	0.00	4.06	0.00	0.00	0.00	0.00
27	41.17	0.00	0.01	0.01	-0.01	4.05	0.01	-0.01	0.00	0.00
28	42.34	0.01	0.01	0.01	0.00	4.05	0.01	0.00	0.00	0.00
29	47.52	0.30	0.03	0.02	0.28	4.33	0.02	0.28	0.00	0.00
30	33.49	0.00	0.00	0.00	0.00	4.33	0.00	0.00	0.00	0.00
31	34.27	0.00	0.00	0.00	0.00	4.33	0.00	0.00	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR DEC - 1989 MONTHLY HEAT INDEX = 0.49

25.26 0.17 0.18 0.15 0.62 4.33 0.12 0.66 0.03 0.00

JAN - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	29.25	0.00	0.00	0.00	0.00	4.33	0.00	0.00	0.00	0.00
2	37.84	0.01	0.01	0.00	0.01	4.33	0.00	0.01	0.00	0.00
3	47.46	0.30	0.03	0.02	0.28	4.61	0.02	0.28	0.00	0.00
4	38.43	0.07	0.01	0.01	0.06	4.67	0.01	0.06	0.00	0.00
5	35.48	0.00	0.00	0.00	0.00	4.67	0.00	0.00	0.00	0.00
6	37.62	0.00	0.01	0.00	0.00	4.67	0.00	0.00	0.00	0.00
7	36.19	0.00	0.00	0.00	0.00	4.67	0.00	0.00	0.00	0.00
8	44.51	0.00	0.02	0.02	-0.02	4.65	0.01	-0.01	0.00	0.00
9	50.45	0.00	0.04	0.03	-0.03	4.63	0.02	-0.02	0.01	0.00
10	49.18	0.00	0.03	0.03	-0.03	4.61	0.02	-0.02	0.01	0.00
11	51.64	0.00	0.04	0.03	-0.03	4.58	0.03	-0.03	0.01	0.00
12	35.01	0.00	0.00	0.00	0.00	4.58	0.00	0.00	0.00	0.00
13	37.17	0.00	0.00	0.00	0.00	4.58	0.00	0.00	0.00	0.00
14	46.74	0.00	0.03	0.02	-0.02	4.56	0.02	0.02	0.01	0.00
15	56.26	0.01	0.06	0.05	-0.04	4.53	0.04	-0.03	0.01	0.00
16	58.55	0.40	0.07	0.06	0.34	4.87	0.06	0.34	0.00	0.00
17	56.16	1.33	0.06	0.05	1.28	6.00	0.05	1.13	0.00	0.16
18	41.96	0.09	0.01	0.01	0.08	6.00	0.01	0.00	0.00	0.08
19	33.62	0.96	0.00	0.00	0.96	6.00	0.00	0.00	0.00	0.96
20	38.62	0.63	0.01	0.01	0.62	6.00	0.01	0.00	0.00	0.62
21	37.82	0.00	0.01	0.00	0.00	6.00	0.00	0.00	0.00	0.00
22	49.69	0.00	0.04	0.03	-0.03	5.97	0.03	-0.03	0.00	0.00
23	52.39	0.00	0.04	0.04	-0.04	5.93	0.04	-0.04	0.00	0.00
24	47.96	0.03	0.03	0.03	0.00	5.93	0.03	0.00	0.00	0.00
25	40.43	0.12	0.01	0.01	0.11	6.00	0.01	0.07	0.00	0.04
26	43.23	0.00	0.02	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
27	47.17	0.00	0.03	0.02	-0.02	5.96	0.02	-0.02	0.00	0.00
28	34.71	0.00	0.00	0.00	0.00	5.96	0.00	0.00	0.00	0.00
29	35.80	0.00	0.00	0.00	0.00	5.96	0.00	0.00	0.00	0.00
30	43.93	0.00	0.02	0.02	-0.02	5.94	0.02	-0.02	0.00	0.00
31	47.40	0.06	0.03	0.02	0.04	5.98	0.02	0.04	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR JAN - 1990 MONTHLY HEAT INDEX = 1.69

43.31 4.01 0.65 0.54 3.49 5.98 0.50 1.67 0.04 1.86

Table 26 (continued)

The Hydrogeology of the Bennett Spring Area

FEB - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	AOJ ET (IN)	P-AOJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	48.53	0.44	0.03	0.03	0.41	6.00	0.03	0.02	0.00	0.39
2	41.52	0.38	0.01	0.01	0.37	6.00	0.01	0.00	0.00	0.37
3	33.58	0.14	0.00	0.00	0.14	6.00	0.00	0.00	0.00	0.14
4	32.77	0.39	0.00	0.00	0.39	6.00	0.00	0.00	0.00	0.39
5	43.48	0.03	0.02	0.02	0.01	6.00	0.02	0.00	0.00	0.01
6	43.70	0.10	0.02	0.02	0.08	6.00	0.02	0.00	0.00	0.08
7	47.19	0.01	0.03	0.02	-0.01	5.99	0.02	-0.01	0.00	0.00
8	56.03	0.03	0.06	0.05	-0.02	5.96	0.05	-0.02	0.00	0.00
9	50.92	0.28	0.04	0.04	0.24	6.00	0.04	0.04	0.00	0.21
10	42.34	0.00	0.01	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
11	51.03	0.00	0.04	0.04	-0.04	5.95	0.04	-0.04	0.00	0.00
12	56.82	0.00	0.06	0.05	-0.05	5.90	0.05	-0.05	0.00	0.00
13	57.46	0.02	0.06	0.06	-0.04	5.86	0.06	-0.04	0.00	0.00
14	40.65	0.29	0.01	0.01	0.28	6.00	0.01	0.14	0.00	0.14
15	36.35	1.28	0.00	0.00	1.28	6.00	0.00	0.00	0.00	1.28
16	31.31	0.17	0.00	0.00	0.17	6.00	0.00	0.00	0.00	0.17
17	30.43	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00
18	42.74	0.00	0.02	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
19	41.56	0.00	0.01	0.01	-0.01	5.97	0.01	-0.01	0.00	0.00
20	38.80	0.00	0.01	0.01	-0.01	5.97	0.01	-0.01	0.00	0.00
21	47.49	0.32	0.03	0.03	0.29	6.00	0.03	0.03	0.00	0.26
22	48.62	0.30	0.03	0.03	0.27	6.00	0.03	0.00	0.00	0.27
23	40.30	0.09	0.01	0.01	0.08	6.00	0.01	0.00	0.00	0.08
24	37.58	0.00	0.01	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
25	29.11	0.00	0.00	0.00	0.00	5.99	0.00	0.00	0.00	0.00
26	46.30	0.00	0.02	0.02	-0.01	5.98	0.02	-0.01	0.00	0.00
27	50.88	0.00	0.04	0.04	0.02	6.00	0.04	0.02	0.00	0.00
28	38.07	0.23	0.01	0.01	0.22	6.00	0.01	0.00	0.00	0.22

MONTHLY AVERAGES AND TOTALS FOR FEB - 1990

MONTHLY HEAT INDEX = 1.52

43.06 4.57 0.58 0.53 4.04 6.00 0.52 0.02 0.00 4.02

MAR - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	AOJ ET (IN)	P-AOJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	29.99	0.14	0.00	0.00	0.14	6.00	0.00	0.00	0.00	0.14
2	39.40	0.00	0.01	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
3	39.88	0.00	0.01	0.01	-0.01	5.98	0.01	-0.01	0.00	0.00
4	46.57	0.00	0.03	0.02	-0.02	5.96	0.02	-0.02	0.00	0.00
5	52.50	0.09	0.04	0.04	0.05	6.00	0.04	0.04	0.00	0.00
6	51.65	0.16	0.04	0.04	0.12	6.00	0.04	0.00	0.00	0.12
7	48.96	0.51	0.03	0.03	0.48	6.00	0.03	0.00	0.00	0.48
8	60.88	0.22	0.08	0.08	0.14	6.00	0.08	0.00	0.00	0.14
9	62.17	0.00	0.08	0.08	-0.08	5.92	0.08	-0.08	0.00	0.00
10	68.74	0.09	0.12	0.11	-0.02	5.89	0.11	-0.02	0.00	0.00
11	66.66	0.17	0.10	0.10	0.07	5.96	0.10	0.07	0.00	0.00
12	68.87	0.38	0.12	0.11	0.27	6.00	0.11	0.04	0.00	0.23
13	65.83	0.25	0.10	0.10	0.15	6.00	0.10	0.00	0.00	0.15
14	60.31	1.31	0.08	0.08	1.23	6.00	0.08	0.00	0.00	1.23
15	51.26	1.13	0.04	0.04	1.09	6.00	0.04	0.00	0.00	1.09
16	50.52	0.00	0.04	0.04	-0.04	5.96	0.04	-0.04	0.00	0.00
17	48.34	0.00	0.03	0.03	-0.03	5.93	0.03	-0.03	0.00	0.00
18	43.20	0.07	0.02	0.02	0.05	5.98	0.02	0.05	0.00	0.00
19	36.76	0.08	0.00	0.00	0.08	6.00	0.00	0.02	0.00	0.06
20	38.99	0.00	0.01	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
21	55.39	0.00	0.06	0.06	-0.06	5.94	0.06	-0.06	0.00	0.00
22	57.42	0.04	0.06	0.06	-0.02	5.91	0.06	-0.02	0.00	0.00
23	41.13	0.10	0.01	0.01	0.09	6.00	0.01	0.09	0.00	0.00
24	27.83	0.32	0.00	0.00	0.32	6.00	0.00	0.00	0.00	0.32
25	29.91	0.13	0.00	0.00	0.13	6.00	0.00	0.00	0.00	0.13
26	43.40	0.09	0.02	0.02	0.07	6.00	0.02	0.00	0.00	0.07
27	43.12	0.03	0.02	0.02	0.01	6.00	0.02	0.00	0.00	0.01
28	44.09	0.46	0.02	0.02	0.44	6.00	0.02	0.00	0.00	0.44
29	49.52	0.08	0.03	0.04	0.04	6.00	0.04	0.00	0.00	0.04
30	46.57	0.22	0.03	0.03	0.19	6.00	0.03	0.00	0.00	0.19
31	52.69	0.03	0.05	0.05	-0.02	5.98	0.05	-0.02	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR MAR - 1990

MONTHLY HEAT INDEX = 3.18

49.12 6.10 1.26 1.26 4.84 5.98 1.26 -0.02 0.00 4.86

Table 26 (continued)

Hydrologic Budget

APR - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	58.93	0.01	0.07	0.07	-0.06	5.92	0.07	-0.06	0.00	0.00
2	50.41	0.00	0.04	0.04	-0.04	5.88	0.04	-0.04	0.00	0.00
3	45.37	0.00	0.02	0.02	-0.02	5.86	0.02	-0.02	0.00	0.00
4	53.54	0.00	0.05	0.05	-0.05	5.81	0.05	-0.05	0.00	0.00
5	47.19	0.19	0.03	0.03	0.16	5.97	0.03	0.16	0.00	0.00
6	39.25	0.16	0.01	0.01	0.15	6.00	0.01	0.03	0.00	0.12
7	42.23	0.00	0.01	0.02	-0.02	5.98	0.02	-0.02	0.00	0.00
8	51.30	0.00	0.04	0.04	-0.04	5.94	0.04	-0.04	0.00	0.00
9	58.56	0.14	0.07	0.07	0.07	6.00	0.07	0.06	0.00	0.01
10	52.42	1.24	0.04	0.05	1.19	6.00	0.05	0.00	0.00	1.19
11	40.38	0.03	0.01	0.01	0.02	6.00	0.01	0.00	0.00	0.02
12	40.77	0.00	0.01	0.01	-0.01	5.99	0.01	-0.01	0.00	0.00
13	47.78	0.37	0.03	0.03	0.34	6.00	0.03	0.01	0.00	0.33
14	52.19	0.27	0.04	0.05	0.22	6.00	0.05	0.00	0.00	0.22
15	55.43	0.00	0.06	0.06	0.02	6.00	0.06	0.00	0.00	0.02
16	58.22	0.07	0.07	0.07	0.00	6.00	0.07	0.00	0.00	0.00
17	46.83	0.31	0.03	0.03	0.28	6.00	0.03	0.00	0.00	0.28
18	51.28	0.01	0.04	0.05	-0.04	5.96	0.05	-0.04	0.00	0.00
19	55.97	0.00	0.06	0.06	-0.06	5.90	0.06	-0.06	0.00	0.00
20	64.09	0.16	0.09	0.10	0.06	5.96	0.10	0.06	0.00	0.00
21	68.14	0.04	0.11	0.13	-0.09	5.87	0.13	-0.09	0.00	0.00
22	69.57	0.00	0.12	0.14	-0.14	5.74	0.13	-0.13	0.00	0.00
23	72.68	0.00	0.14	0.15	-0.15	5.59	0.15	-0.15	0.01	0.00
24	72.95	0.00	0.14	0.16	-0.16	5.45	0.15	-0.15	0.01	0.00
25	72.34	0.00	0.13	0.15	-0.15	5.31	0.14	-0.14	0.01	0.00
26	73.28	0.00	0.14	0.16	-0.16	5.17	0.14	-0.14	0.02	0.00
27	69.15	0.55	0.12	0.13	0.42	5.58	0.13	0.42	0.00	0.00
28	55.13	0.25	0.05	0.06	0.19	5.77	0.06	0.19	0.00	0.00
29	66.63	0.00	0.10	0.12	-0.12	5.65	0.12	-0.12	0.00	0.00
30	56.05	0.02	0.06	0.07	-0.05	5.61	0.06	-0.04	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR APR - 1990

MONTHLY HEAT INDEX = 4.75

56.27	3.90	1.93	2.16	1.74	5.61	2.10	-0.37	0.06	2.18
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MAY - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	56.30	0.10	0.06	0.07	0.03	5.64	0.07	0.03	0.00	0.00
2	55.22	0.13	0.05	0.06	0.07	5.71	0.06	0.07	0.00	0.00
3	62.91	1.84	0.09	0.10	1.74	6.00	0.10	0.29	0.00	1.45
4	60.26	0.55	0.08	0.09	0.46	6.00	0.09	0.00	0.00	0.46
5	57.63	0.03	0.06	0.08	-0.05	5.95	0.08	-0.05	0.00	0.00
6	61.64	0.02	0.08	0.10	-0.08	5.88	0.09	-0.07	0.00	0.00
7	64.27	0.00	0.09	0.11	-0.11	5.77	0.11	-0.11	0.00	0.00
8	66.82	0.00	0.11	0.12	-0.12	5.65	0.12	-0.12	0.00	0.00
9	61.81	0.05	0.08	0.10	-0.05	5.61	0.09	-0.04	0.00	0.00
10	51.85	0.02	0.04	0.05	-0.03	5.58	0.05	-0.03	0.00	0.00
11	50.01	0.12	0.04	0.05	0.07	5.65	0.05	0.07	0.00	0.00
12	60.52	0.79	0.08	0.09	0.70	6.00	0.09	0.35	0.00	0.35
13	61.84	0.05	0.08	0.10	-0.05	5.95	0.10	-0.05	0.00	0.00
14	64.62	0.18	0.09	0.11	0.07	6.00	0.11	0.05	0.00	0.02
15	72.30	0.50	0.13	0.16	0.34	6.00	0.16	0.00	0.00	0.34
16	72.32	0.96	0.13	0.16	0.80	6.00	0.16	0.00	0.00	0.80
17	59.83	0.22	0.07	0.09	0.13	6.00	0.09	0.00	0.00	0.13
18	60.88	0.04	0.08	0.09	-0.05	5.95	0.09	-0.05	0.00	0.00
19	65.08	0.40	0.10	0.12	0.28	6.00	0.12	0.05	0.00	0.23
20	71.38	0.10	0.13	0.16	-0.06	5.94	0.16	-0.06	0.00	0.00
21	64.60	0.88	0.09	0.11	0.77	6.00	0.11	0.06	0.00	0.71
22	60.67	0.00	0.08	0.09	-0.09	5.91	0.09	-0.09	0.00	0.00
23	62.44	0.00	0.08	0.10	-0.10	5.81	0.10	-0.10	0.00	0.00
24	64.57	0.04	0.09	0.12	-0.08	5.73	0.11	-0.07	0.00	0.00
25	75.35	0.21	0.15	0.18	0.03	5.76	0.18	0.03	0.00	0.00
26	64.85	3.39	0.10	0.12	3.27	6.00	0.12	0.24	0.00	3.03
27	61.69	0.39	0.08	0.10	0.29	6.00	0.10	0.00	0.00	0.29
28	64.05	0.04	0.09	0.11	-0.07	5.93	0.11	-0.07	0.00	0.00
29	65.92	0.01	0.10	0.12	-0.11	5.81	0.12	-0.11	0.00	0.00
30	67.60	0.02	0.11	0.13	-0.11	5.70	0.13	-0.11	0.00	0.00
31	65.22	0.15	0.10	0.12	0.03	5.73	0.12	0.03	0.00	0.00

MONTHLY AVERAGES AND TOTALS FOR MAY - 1990

MONTHLY HEAT INDEX = 6.73

63.07	11.23	2.76	3.31	7.92	5.73	3.29	0.12	0.02	7.81
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Table 26 (continued)

The Hydrogeology of the Bennett Spring Area

JUN - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	73.61	0.07	0.14	0.17	-0.10	5.64	0.17	-0.10	0.00	0.00
2	73.01	0.02	0.14	0.17	-0.15	5.50	0.16	-0.14	0.01	0.00
3	68.79	0.00	0.12	0.14	-0.14	5.36	0.13	-0.13	0.01	0.00
4	60.32	0.00	0.08	0.09	-0.09	5.28	0.08	-0.08	0.01	0.00
5	67.22	0.00	0.11	0.13	-0.13	5.16	0.12	-0.12	0.02	0.00
6	75.99	0.07	0.15	0.19	-0.12	5.06	0.17	-0.10	0.02	0.00
7	77.15	0.00	0.16	0.20	-0.20	4.89	0.17	-0.17	0.03	0.00
8	79.24	0.03	0.17	0.21	-0.18	4.74	0.18	-0.15	0.03	0.00
9	73.87	0.46	0.14	0.18	0.20	5.03	0.18	0.20	0.00	0.00
10	73.15	0.01	0.14	0.17	-0.16	4.89	0.15	-0.14	0.03	0.00
11	74.25	0.00	0.14	0.18	-0.18	4.75	0.15	-0.15	0.03	0.00
12	76.95	0.00	0.16	0.20	-0.20	4.59	0.16	-0.16	0.04	0.00
13	80.50	0.00	0.18	0.23	-0.23	4.42	0.17	-0.17	0.05	0.00
14	70.85	0.41	0.13	0.16	0.25	4.67	0.16	0.25	0.00	0.00
15	79.34	0.20	0.17	0.22	-0.02	4.66	0.21	-0.01	0.00	0.00
16	80.47	0.00	0.18	0.23	-0.23	4.48	0.18	-0.18	0.05	0.00
17	82.41	0.00	0.19	0.24	-0.24	4.30	0.18	-0.18	0.06	0.00
18	83.15	0.00	0.20	0.25	-0.25	4.12	0.18	-0.18	0.07	0.00
19	77.96	0.16	0.17	0.21	-0.05	4.09	0.19	-0.03	0.01	0.00
20	75.97	0.34	0.15	0.19	0.15	4.24	0.19	0.15	0.00	0.00
21	73.63	0.09	0.14	0.18	-0.09	4.18	0.15	-0.06	0.03	0.00
22	70.50	0.37	0.12	0.15	0.22	4.40	0.15	0.22	0.00	0.00
23	67.43	0.07	0.11	0.13	-0.06	4.35	0.12	-0.05	0.02	0.00
24	69.22	0.00	0.12	0.15	-0.15	4.24	0.11	-0.11	0.04	0.00
25	73.51	0.26	0.14	0.17	0.09	4.33	0.17	0.09	0.00	0.00
26	77.39	0.13	0.16	0.20	-0.07	4.28	0.18	-0.06	0.02	0.00
27	78.03	0.02	0.17	0.21	-0.19	4.14	0.15	-0.13	0.05	0.00
28	79.96	0.00	0.18	0.22	-0.22	3.99	0.15	-0.15	0.07	0.00
29	81.70	0.00	0.19	0.24	-0.24	3.83	0.16	-0.16	0.08	0.00
30	79.89	0.00	0.18	0.22	-0.22	3.69	0.14	-0.14	0.08	0.00

MONTHLY AVERAGES AND TOTALS FOR JUN - 1990

MONTHLY HEAT INDEX = 10.66

75.18 2.71 4.53 5.62 -2.91 3.69 4.75 -2.04 0.87 0.00

JUL - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	81.88	0.00	0.19	0.24	-0.24	3.55	0.15	-0.15	0.09	0.00
2	85.60	0.00	0.21	0.26	-0.26	3.39	0.15	-0.15	0.11	0.00
3	86.18	0.00	0.21	0.26	-0.26	3.24	0.15	-0.15	0.11	0.00
4	86.34	0.00	0.21	0.27	-0.27	3.10	0.14	-0.14	0.12	0.00
5	85.77	0.09	0.21	0.26	-0.17	3.01	0.18	-0.09	0.08	0.00
6	82.86	0.13	0.20	0.24	-0.11	2.95	0.19	-0.06	0.06	0.00
7	81.38	0.01	0.19	0.23	-0.22	2.86	0.12	-0.11	0.11	0.00
8	83.55	0.00	0.20	0.25	-0.25	2.73	0.12	-0.12	0.13	0.00
9	84.05	0.00	0.20	0.25	-0.25	2.61	0.11	-0.11	0.14	0.00
10	84.79	0.00	0.21	0.25	-0.25	2.50	0.11	-0.11	0.14	0.00
11	79.25	1.15	0.17	0.21	0.94	3.44	0.21	0.94	0.00	0.00
12	70.98	0.78	0.13	0.16	0.62	4.07	0.16	0.62	0.00	0.00
13	66.49	0.82	0.10	0.13	0.69	4.76	0.13	0.69	0.00	0.00
14	60.48	0.03	0.08	0.09	-0.06	4.71	0.08	-0.05	0.01	0.00
15	68.33	0.02	0.11	0.14	-0.12	4.62	0.11	-0.09	0.03	0.00
16	75.27	0.00	0.15	0.18	-0.18	4.47	0.14	-0.14	0.04	0.00
17	74.05	0.00	0.14	0.17	-0.17	4.34	0.13	-0.13	0.04	0.00
18	77.70	0.00	0.16	0.20	-0.20	4.20	0.14	-0.14	0.05	0.00
19	78.86	0.00	0.17	0.21	-0.21	4.06	0.15	-0.15	0.06	0.00
20	79.88	0.00	0.18	0.22	-0.22	3.91	0.15	-0.15	0.07	0.00
21	78.96	0.30	0.17	0.21	0.09	4.00	0.21	0.09	0.00	0.00
22	68.88	0.28	0.12	0.14	0.14	4.14	0.14	0.14	0.00	0.00
23	70.73	0.02	0.13	0.15	-0.13	4.05	0.11	-0.09	0.04	0.00
24	72.01	0.01	0.13	0.16	-0.15	3.95	0.11	-0.10	0.05	0.00
25	74.90	0.09	0.15	0.18	-0.09	3.89	0.15	-0.06	0.03	0.00
26	74.09	1.37	0.14	0.17	1.20	5.09	0.17	1.20	0.00	0.00
27	80.05	0.51	0.18	0.21	0.30	5.39	0.21	0.30	0.00	0.00
28	80.94	0.00	0.19	0.22	-0.22	5.19	0.20	-0.20	0.02	0.00
29	77.07	0.00	0.16	0.19	-0.19	5.02	0.17	-0.17	0.03	0.00
30	75.63	0.00	0.15	0.18	-0.18	4.87	0.15	-0.15	0.03	0.00
31	71.81	0.00	0.13	0.16	-0.16	4.75	0.13	-0.13	0.03	0.00

MONTHLY AVERAGES AND TOTALS FOR JUL - 1990

MONTHLY HEAT INDEX = 11.90

77.38 5.61 5.08 6.19 -0.58 4.75 4.56 1.05 1.63 0.00

Table 26 (continued)

Hydrologic Budget

AUG - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	74.10	0.00	0.14	0.17	-0.17	4.61	0.13	-0.13	0.04	0.00
2	76.46	0.00	0.16	0.19	-0.19	4.47	0.14	-0.14	0.04	0.00
3	78.05	0.09	0.17	0.20	-0.69	5.16	0.20	0.69	0.00	0.00
4	75.56	0.87	0.15	0.18	-0.69	5.86	0.18	0.69	0.00	0.00
5	70.14	0.24	0.12	0.14	-0.10	5.95	0.14	0.10	0.00	0.00
6	67.67	0.00	0.11	0.13	-0.13	5.83	0.13	-0.13	0.00	0.00
7	63.06	0.00	0.09	0.10	-0.10	5.73	0.10	-0.10	0.00	0.00
8	66.50	0.00	0.10	0.12	-0.12	5.61	0.12	-0.12	0.01	0.00
9	70.40	0.00	0.12	0.14	-0.14	5.48	0.13	-0.13	0.01	0.00
10	72.06	0.00	0.13	0.15	-0.15	5.34	0.14	-0.14	0.01	0.00
11	68.34	0.03	0.11	0.13	-0.10	5.25	0.12	-0.09	0.01	0.00
12	72.13	0.23	0.13	0.15	0.08	5.32	0.15	0.08	0.00	0.00
13	71.88	0.20	0.13	0.15	0.05	5.37	0.15	0.05	0.00	0.00
14	73.14	0.00	0.14	0.16	-0.16	5.23	0.14	-0.14	0.02	0.00
15	75.67	0.21	0.15	0.17	0.04	5.27	0.17	0.04	0.00	0.00
16	77.81	0.31	0.16	0.19	0.12	5.39	0.19	0.12	0.00	0.00
17	80.35	0.07	0.18	0.21	-0.14	5.27	0.19	-0.12	0.01	0.00
18	80.89	0.00	0.18	0.21	-0.21	5.08	0.18	-0.18	0.03	0.00
19	80.31	0.13	0.18	0.20	-0.07	5.02	0.19	-0.06	0.01	0.00
20	77.60	0.10	0.16	0.18	-0.08	4.95	0.17	-0.07	0.01	0.00
21	74.93	0.00	0.15	0.17	-0.17	4.81	0.14	-0.14	0.03	0.00
22	74.01	0.00	0.14	0.16	-0.16	4.68	0.13	-0.13	0.03	0.00
23	78.67	0.00	0.17	0.19	-0.19	4.53	0.15	-0.15	0.04	0.00
24	83.34	0.00	0.20	0.22	-0.22	4.37	0.17	-0.17	0.05	0.00
25	84.29	0.00	0.20	0.23	-0.23	4.20	0.17	-0.17	0.06	0.00
26	80.40	0.00	0.22	0.25	-0.25	4.03	0.17	-0.17	0.07	0.00
27	84.66	0.00	0.21	0.23	-0.23	3.88	0.15	-0.15	0.07	0.00
28	85.54	0.00	0.21	0.23	-0.23	3.73	0.15	-0.15	0.08	0.00
29	84.57	0.00	0.21	0.23	-0.23	3.59	0.14	-0.14	0.09	0.00
30	76.68	0.00	0.16	0.17	-0.17	3.48	0.10	-0.10	0.07	0.00
31	78.37	0.00	0.17	0.18	-0.18	3.38	0.11	-0.11	0.08	0.00

MONTHLY AVERAGES AND TOTALS FOR AUG - 1990

MONTHLY HEAT INDEX = 11.47

76.32	3.28	4.88	5.53	-2.25	3.38	4.65	-1.37	0.88	0.00
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SEP - 1990

DAY	TEMP (F)	PREC (IN)	POT ET (IN)	ADJ ET (IN)	P-ADJ ET (IN)	SMS (IN)	ACT ET (IN)	CHANGE SMS (IN)	DEFICIT (IN)	SURPLUS (IN)
1	83.37	0.00	0.20	0.22	-0.22	3.25	0.12	-0.12	0.09	0.00
2	80.76	0.00	0.18	0.20	-0.20	3.15	0.11	-0.11	0.09	0.00
3	83.52	0.00	0.20	0.22	-0.22	3.03	0.11	-0.11	0.10	0.00
4	85.84	0.00	0.21	0.23	-0.23	2.92	0.12	-0.12	0.11	0.00
5	85.64	0.00	0.21	0.23	-0.23	2.81	0.11	-0.11	0.12	0.00
6	86.79	0.08	0.22	0.23	-0.15	2.74	0.15	-0.07	0.08	0.00
7	85.55	0.03	0.21	0.22	-0.19	2.65	0.12	-0.09	0.11	0.00
8	76.91	0.08	0.16	0.17	-0.09	2.61	0.12	-0.04	0.05	0.00
9	78.89	0.00	0.17	0.18	-0.18	2.53	0.08	-0.08	0.10	0.00
10	79.22	0.13	0.17	0.18	-0.05	2.51	0.15	-0.07	0.03	0.00
11	73.04	0.26	0.14	0.15	0.11	2.62	0.15	0.11	0.00	0.00
12	74.47	0.21	0.15	0.15	0.06	2.68	0.15	0.06	0.00	0.00
13	74.94	0.04	0.15	0.16	-0.12	2.63	0.09	-0.05	0.06	0.00
14	75.83	0.07	0.15	0.16	-0.09	2.59	0.11	-0.04	0.05	0.00
15	65.94	0.00	0.10	0.11	-0.11	2.54	0.05	-0.05	0.06	0.00
16	66.00	0.00	0.10	0.11	-0.11	2.50	0.04	-0.04	0.06	0.00
17	66.01	0.03	0.10	0.10	-0.07	2.47	0.06	0.03	0.04	0.00
18	68.92	0.59	0.12	0.12	0.47	2.94	0.12	0.47	0.00	0.00
19	70.28	0.23	0.12	0.13	0.10	3.04	0.13	0.10	0.00	0.00
20	66.53	0.02	0.10	0.11	-0.09	3.00	0.06	-0.04	0.04	0.00
21	69.15	0.54	0.12	0.12	0.42	3.42	0.12	0.42	0.00	0.00
22	62.13	0.16	0.08	0.08	0.08	3.49	0.08	0.08	0.00	0.00
23	52.02	0.00	0.04	0.04	-0.04	3.47	0.03	-0.03	0.02	0.00
24	53.91	0.00	0.05	0.05	-0.05	3.44	0.03	-0.03	0.02	0.00
25	68.11	0.00	0.11	0.11	-0.11	3.38	0.06	-0.06	0.05	0.00
26	73.20	0.00	0.14	0.14	-0.14	3.30	0.08	-0.08	0.06	0.00
27	74.08	0.00	0.14	0.14	-0.14	3.22	0.08	-0.08	0.06	0.00
28	75.15	0.00	0.15	0.15	-0.15	3.14	0.08	-0.08	0.07	0.00
29	69.05	0.01	0.12	0.12	-0.11	3.08	0.07	-0.06	0.05	0.00
30	63.67	0.03	0.09	0.09	-0.06	3.05	0.06	-0.03	0.03	0.00

MONTHLY AVERAGES AND TOTALS FOR SEP - 1990

MONTHLY HEAT INDEX = 9.96

72.96	2.51	4.21	4.40	-1.09	3.05	2.83	-0.32	1.57	0.00
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YEARLY AVERAGES AND TOTALS

57.59	48.52	29.83	33.13	15.43	3.05	25.71	2.14	7.43	20.73
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Table 26 (continued)

THE POTENTIAL FOR CONTAMINATION IN THE BENNETT SPRING RECHARGE AREA

The quality of water at any spring is dependent upon many factors. Natural water quality is primarily a function of bedrock type; most of the dissolved inorganic constituents in groundwater are derived from the rock the water has come in contact with. Bennett Spring discharges from an aquifer primarily composed of dolomite, and its water quality reflects this. The water is a moderately-mineralized, calcium-magnesium-bicarbonate type, and its dissolved-solids load consists mostly of these three constituents. Other inorganic constituents, such as sulfate, chloride, sodium, potassium, iron, manganese, and silica are also present in relatively low amounts. Nutrients such as nitrate and phosphate are present in low concentrations at most springs, and may be from either natural or man-made sources.

Bacteria and smaller organisms can easily enter groundwater with discrete recharge, and are readily transported through most Ozark spring systems. Rapid groundwater movement through relatively large openings offers little or no filtration, so microorganisms are likely to be present in the water at any spring.

With the exception of bacteria, natural conditions rarely lead to water-quality problems at Ozark springs. Such problems are most often associated with activities in the recharge areas that introduce contaminants into the groundwater. As part of this study, a preliminary evaluation of contamination potential was made for the Niangua River, Dry Auglaize Creek, and Osage Fork basins in Laclede, Dallas, Wright, and Webster counties. This evaluation includes existing information on file with the Department of Natural Resources Division of Environmental Quality, including permitted wastewater treatment facilities, permitted solid waste disposal facilities, and known hazardous-waste sites. It also includes information on transportation corridors including major highways, railroads, and pipelines. Features identified as potential contaminant sources are shown in figure 38.

The Missouri Registry of Confirmed Abandoned or Uncontrolled Hazardous Waste Disposal Sites (Missouri Division of Environmental Quality, June 1990) lists no sites within the study area in Dallas, Webster, and Wright counties. One site is listed in Laclede County in sec. 12, T. 33 N., R. 17 W., about 3 miles northeast of Phillipsburg along the Burlington Northern Railroad. Here, a railroad tank car carrying flammable phosphorous derailed and caught fire. The fire was extinguished by burying the car; the site is paved, fenced, and posted.

As of July 1, 1990, there are no permitted hazardous waste treatment, storage, or disposal facilities in the study area, and there are currently no operating permitted solid waste treatment facilities, including sanitary landfills, in Dallas and Laclede counties. Permitted sanitary landfills are operating in Webster County (Webster County Sanitary Landfill) and Wright County (Hartville Sanitary Landfill), but both are outside of the Niangua and Osage Fork basins. Three permitted landfills have operated in Dallas and Laclede counties, but are closed. Dallas County Sanitary Landfill operated in sec. 34, T. 35 N., R. 19 W., about 7 miles northeast of Buffalo, is on a tributary of Durlington Creek, and is not within the Bennett Spring recharge area. Two permitted sanitary landfills, both now closed, operated in the Lebanon area. City of Lebanon Sanitary Landfill operated in parts of sections 15 and 16, T. 34 N., R. 16 W. The site is in upper Goodwin Hollow, southeast of the creek, in an area containing numerous sinkholes. The landfill is within recharge areas of Bennett Spring and Sweet Blue Spring. Colbeck Sanitary Landfill operated in Laclede County 4 miles east of Lebanon in sec. 9, T. 34 N., R. 15 W. The site is in the upper Mill Creek watershed, and may be within the Bennett Spring recharge area.

There are several wastewater treatment facilities with NPDES (National Pollutant Discharge Elimination System) permits in the study area that are regulated by the Department of Natural Re-



Photo 15. *Improper disposal of trash and other waste products in sinkholes can degrade groundwater quality.*

sources. These facilities include municipal, industrial, and some privately owned wastewater treatment systems. These facilities are permitted to discharge set quantities of treated wastewater that meet applicable discharge standards established for the receiving stream. These sites are shown in figure 38.

Six pipelines cross parts of Dallas, Laclede, Wright and Webster counties; four of the pipelines are currently in use (fig. 38). Shell Pipeline Corporation's Ozark Pipeline is a 22-inch diameter petroleum line that transports crude oil. The line passes through Dallas and Laclede counties and crosses numerous losing streams including Spring Hollow about 2 miles southeast of Bennett Spring. A second Shell pipeline, an older 10-inch diameter line, parallels the Ozark Pipeline but is not currently used. The Explorer Pipeline roughly parallels the Ozark Pipeline; the two are typically less than a mile apart across the study area. The Explorer line is 24 inches in diameter, and transports refined petroleum products including gasoline, fuel oil, diesel fuel, and jet fuel. About 9 miles of both the Ozark and Explorer pipelines are within the Bennett Spring recharge area, and they also cross recharge areas of Sand, Famous Blue, Sweet Blue, and Hahatonka springs.

The Continental Pipeline, Conoco, Inc., passes through parts of Laclede, Dallas, and Webster counties south of the Ozark and Explorer pipelines, and crosses the Bennett Spring recharge area. The Continental Pipeline is actually two, 10-inch diameter lines used to transport refined petroleum products including gasoline, fuel oil, aviation fuels, and propane. About a 14-mile reach of these lines is within Bennett Spring's recharge area, and the lines also cross areas providing recharge to Johnson-Wilkerson Spring, Sweet Blue Spring, and Hahatonka Spring.

The remaining pipeline, previously used by Williams Pipeline Company for transporting ammonium nitrate and urea fertilizer, passes through Wright and Webster counties. This line is now owned by Williams Telecommunications, who plan to use it as a fiber-optics cable conduit. It is no longer used to transport fluids.

Several major highways cross the study area, including the recharge area for Bennett Spring. About 26 miles of Interstate-44, from near

Marshfield to Lebanon, crosses the Bennett Spring recharge area. The Burlington Northern Railroad roughly parallels Interstate 44 through the same area. Sections of Missouri highways 64, 32, and 5, plus numerous secondary highways and county roads, also cross the recharge area.

None of the waste disposal sites, wastewater treatment facilities, pipelines, and transportation corridors discussed above are known to be contributing contaminants. They are simply the more obvious potential contaminant sources. Numerous additional potential contaminant sources exist, including animal waste lagoons, underground storage tanks, and private residential septic systems.

The effects that an environmental accident could have in the study area depend greatly on the type of contaminant released, contaminant quantity, and location. Contaminants released into a diffuse recharge setting, well away from any discrete recharge feature such as a losing stream or sinkhole, may cause locally severe groundwater contamination, or, if adjacent to a gaining stream, surface-water contamination. Subsurface contaminant movement will likely be slow in this setting, and contaminants would likely affect nearby private wells. If action is quickly taken, at least some contaminant recovery would be possible which would mitigate damages from the spill. The contaminants would likely be fairly well dispersed by the time they entered larger spring-system conduits. Contaminants released into a diffuse recharge setting in the Bennett Spring recharge area would likely arrive at the spring in low concentrations, but would affect water quality for an extended time. At springs with lower discharges, contaminant concentrations would likely be higher.

Contaminants introduced into discrete recharge features will move rapidly into the subsurface and will, within a relatively short time, begin to affect the quality of water discharging from the receiving spring. However, because the discrete recharge follows well-defined conduit-type flow paths, water in the aquifer adjacent to the conduits may not be affected. A groundwater conduit functions much like a horizontal well; water is induced to move toward it and not away from it. Of course, periods of high recharge following heavy precipitation may increase the head pressure in the conduit to

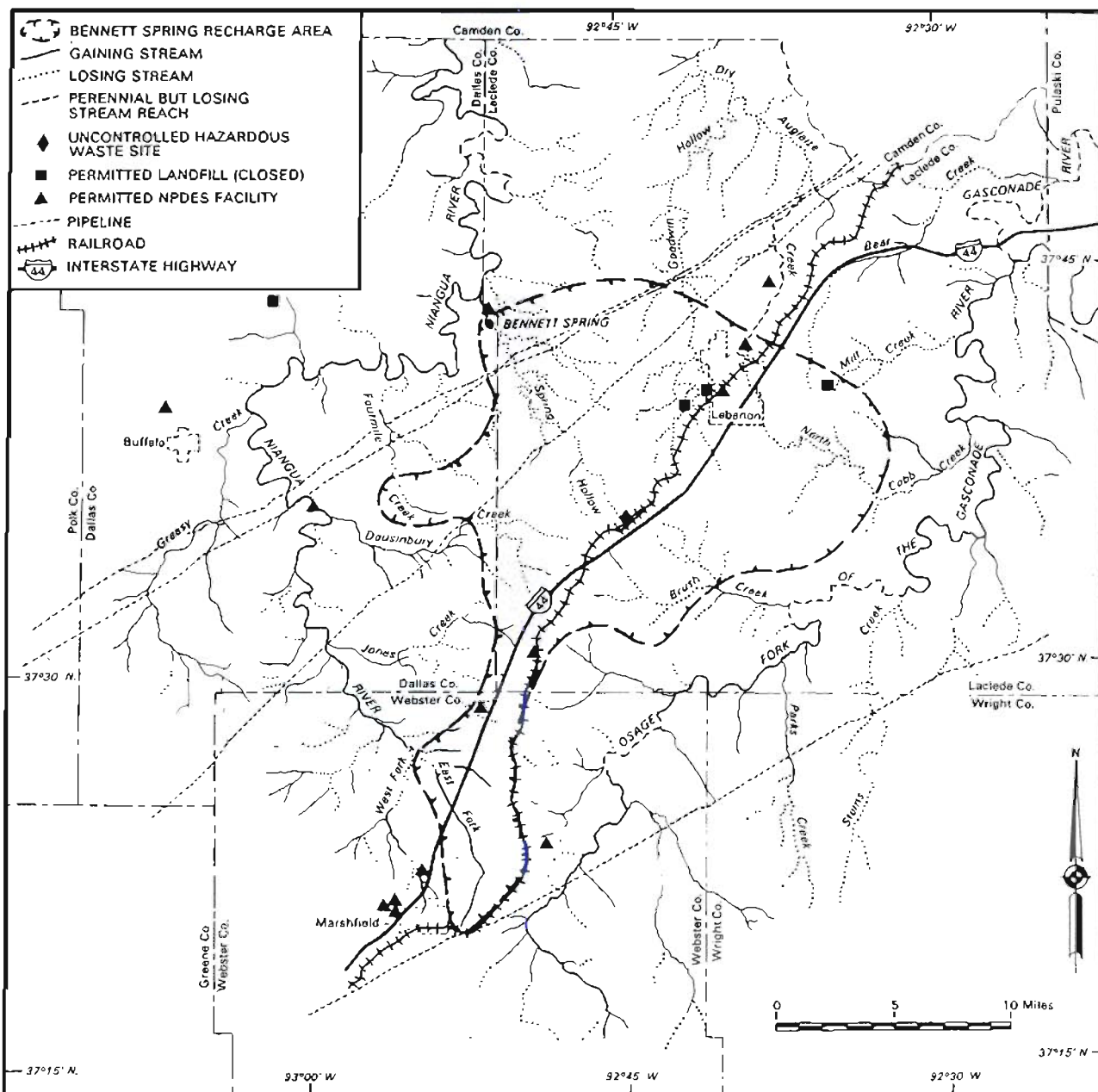


Figure 38. Potential contaminant sources in the Bennett Spring area.

where it is greater than the head pressure in the adjacent aquifer. As a result, water within the conduit will flow into the adjacent aquifer. However, as the recharge is channelled away, pressure in the conduit will decrease and water that moved from it into the aquifer will reverse and flow back to the conduit. There are several instances in Missouri where contaminants were accidentally introduced into a losing stream or sinkhole, and affected the quality of water at a spring some distance away. However, water samples from wells between the contaminated site and the spring showed the wells were not affected.

Groundwater velocities measured from dye tracing in the study area range from less than 0.25 mi/day to a high of over 1.25 mi/day. Obviously, the

chances of capturing and retaining spilled contaminants in a discrete recharge setting are very poor. Contaminant concentrations at the receiving spring will probably be relatively high, and depending on the recharge characteristics of the spring and the chemical characteristics of the spilled material, contaminants may affect the spring for a few weeks or a much longer period of time. Several of the potential contaminant sources in Bennett Spring's recharge area are petroleum pipelines carrying crude oil as well as refined petroleum products. A major release from any of these lines, especially where they cross losing streams, would likely cause severe long-term water-quality degradation at Bennett Spring.

HYDROLOGIC CHARACTERISTICS OF BENNETT SPRING AND ITS RECHARGE AREA

The hydrologic characteristics of Bennett Spring, including its recharge and discharge characteristics, are to a great extent controlled by recharge area size, recharge type and rate, and the geometry of the conduit system channelling water to the spring. The information collected during this study cannot answer all of the questions about the Bennett Spring system, but it certainly allows a much better understanding of its hydrology.

Dye tracing and potentiometric map analysis indicates a recharge area of approximately 265 mi². Average discharge at Bennett Spring is approximately 165 ft³/sec, allowing for an average discharge of 5 ft³/sec for Spring Hollow upstream from Bennett Spring. Based on these figures, the spring system has an average annual recharge rate of 8.5 inches; on the average, of the total precipitation occurring over the recharge area, 8.5 inches of precipitation enters the subsurface to recharge Bennett Spring. However, it is doubtful that this recharge rate is uniform over the entire recharge area. Most of the recharge occurs in losing-stream watersheds; water-loss rates vary between each of the losing streams. For example, flow measurements in Spring Hollow show that

very little water leaves the watershed by surface flow; nearly all of the water is channelled underground to emerge at Bennett Spring. Conversely, upper Fourmile Creek which also provides recharge to Bennett Spring has a higher surface-water runoff rate, and consequently a lower groundwater-recharge rate.

A significant part of the Bennett Spring recharge area also provides recharge to other springs. The East Fork Niangua River recharges both Bennett Spring and Jake George Springs, and upper Goodwin Hollow provides recharge to Sweet Blue Spring as well as Bennett Spring. Presently, it is not possible to measure the amounts of water provided from these two areas to each of the three springs, but obviously the amount of water Bennett Spring receives from these areas is considerably less than if they provided recharge only to Bennett Spring. Additionally, the losing reach of the East Fork is relatively short, and flow observations made during this study show that considerable surface-water runoff does occur in this reach, effectively decreasing the amount of groundwater recharge in this part of the recharge area.

The part of the Bennett Spring recharge area with the highest groundwater-recharge rate consists of about 156 mi², and includes Spring Hollow, upper Dousinbury Creek, upper Goodwin Hollow, upper North Cobb Creek, and upper Brush Creek watersheds. Recharge in these watersheds, which comprise about 59 percent of the total recharge area, likely provide about 80 percent of Bennett Spring recharge.

Bennett Spring discharge is dependent on recharge. The volume of recharge is dependent on precipitation, soil characteristics, evapotranspiration, and the presence of discrete recharge features such as sinkholes and losing streams. The long-term hydrologic balance, which was based on a soil moisture field capacity of 6 inches, showed an average surplus moisture of about 13.9 inches per year, slightly higher than average annual runoff measured at surface-water gaging stations in the area. Surplus moisture, however, represents the amount of water available for groundwater recharge and surface-water runoff. During dry years in some losing-stream watersheds, all of the surplus moisture may become groundwater recharge. During wet years, the same watersheds may have a significant volume of surface-water runoff. Figure 39 shows weighted water year precipitation for the Bennett Spring recharge area plotted against average annual discharge at Bennett Spring for water years 1966 through 1990. The relationship between rainfall and discharge can be seen, but correlation is relatively poor. Groundwater recharge is dependent on rainfall, but recharge also depends on when the precipitation occurs, the amount of soil moisture in storage, temperature, and other factors. For example, a year with above-average precipitation may produce less surplus moisture than a drier year if most of the precipitation occurred as relatively small but frequent rainfall events during hot weather when soil moisture storage was low and evapotranspiration was high.

Figure 40 shows calculated water year surplus moisture plotted against discharge at Bennett Spring for water years 1966 through 1990. It shows less data scattering and much better correlation of data than figure 39. Much of the scattering is a reflection of the aquifer storage characteristics in the Bennett Spring recharge area. Water discharging from Bennett Spring consists of discrete recharge, which is primarily responsible for

the rapid increases in discharge after significant recharge events, and diffuse recharge which moves much more slowly through the aquifer and provides spring flow during dry weather. For example, average discharge at Bennett Spring during a dry year will exceed the discharge calculated from figure 40 if the previous year had normal or above normal recharge. Average discharge during a very wet year will be less than calculated if it follows a dry year. Thus, aquifer storage is an important factor in Bennett Spring discharge. Figure 41 shows average daily discharge at Bennett Spring during two water years with extremely different recharge amounts. Between water years 1965-1966 and 1989-1990, water year 1976-1977 had the lowest surplus moisture and Bennett Spring had its lowest average annual flow. Surplus moisture during this year was calculated at 6.96 inches, 8 inches below average for the 25-year period. Average discharge at Bennett Spring for the year was 105 ft³/sec. There were very few rainfall events that generated discrete recharge, and most of the spring discharge during the year was derived from water in storage in the aquifer. Conversely, water year 1984-1985 had the highest precipitation and second highest calculated surplus moisture during the period, 52.68 inches and 27.61 inches, respectively. Bennett Spring's average discharge during this year was 296 ft³/sec. The hydrograph shows considerable discrete recharge from frequent rainfall events throughout most of the water year, and many of the hydrograph peaks likely include significant runoff from Spring Hollow upstream from Bennett Spring.

The hydrologic budgets are a useful tool for estimating the amount of surplus moisture available during a given year, but do not always show when recharge occurs. This is most common in the long-term hydrologic budget, which uses monthly precipitation and temperature data, but even the water year 1989-1990 hydrologic budget, which used daily temperature and precipitation data, failed to show several recharge events. Figure 42 shows weighted recharge area precipitation, surplus moisture, and discharge at Bennett Spring for water year 1989-1990. The spring hydrograph is corrected for surface-water runoff from Spring Hollow. Several rainfall events in November, July, and August generated discrete recharge, as evidenced by hydrograph peaks at Bennett Spring. However, based on hydrologic budget calculations, no surplus moisture was gen-

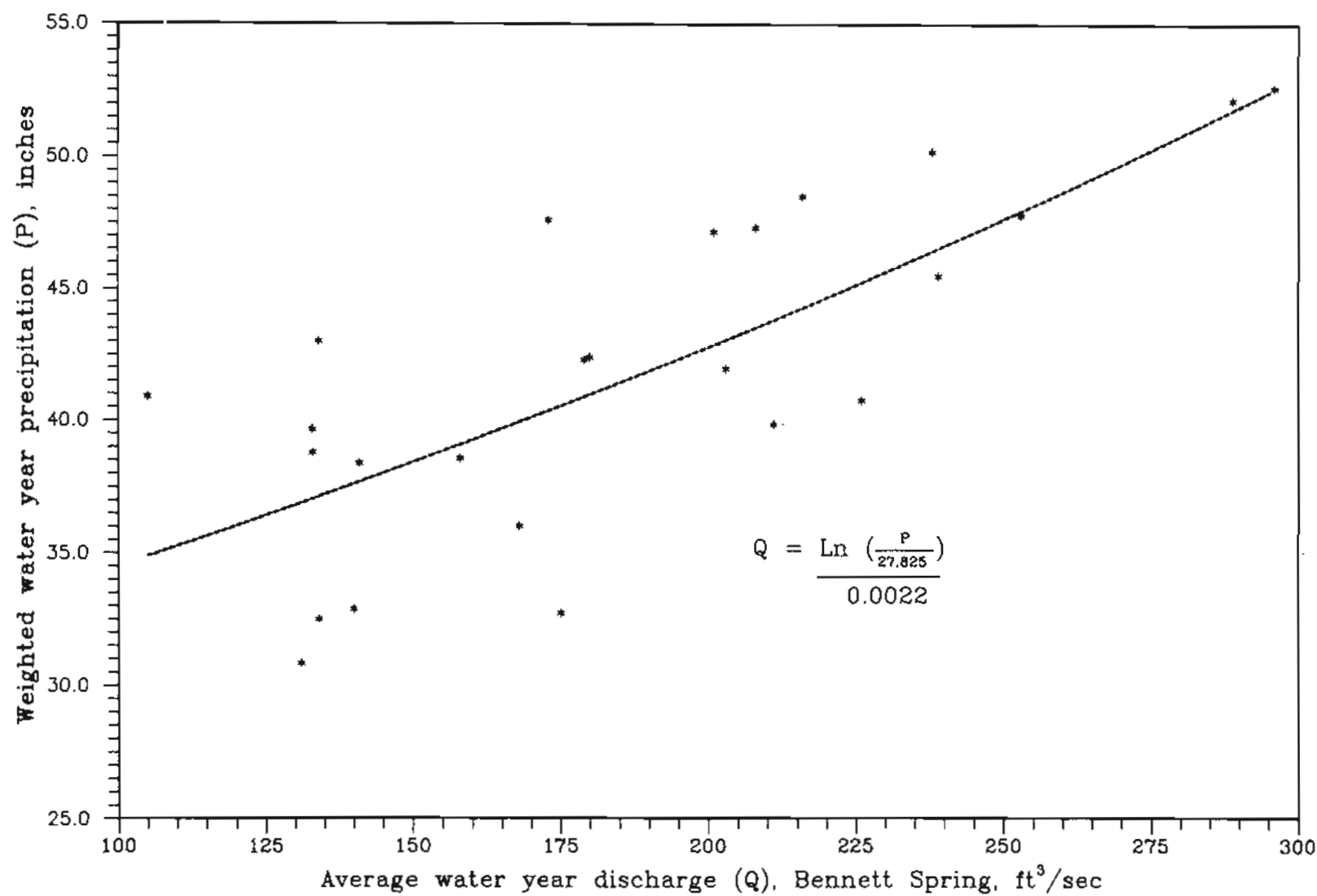


Figure 39: Weighted precipitation versus discharge, water years 1966-1990, Bennett Spring.

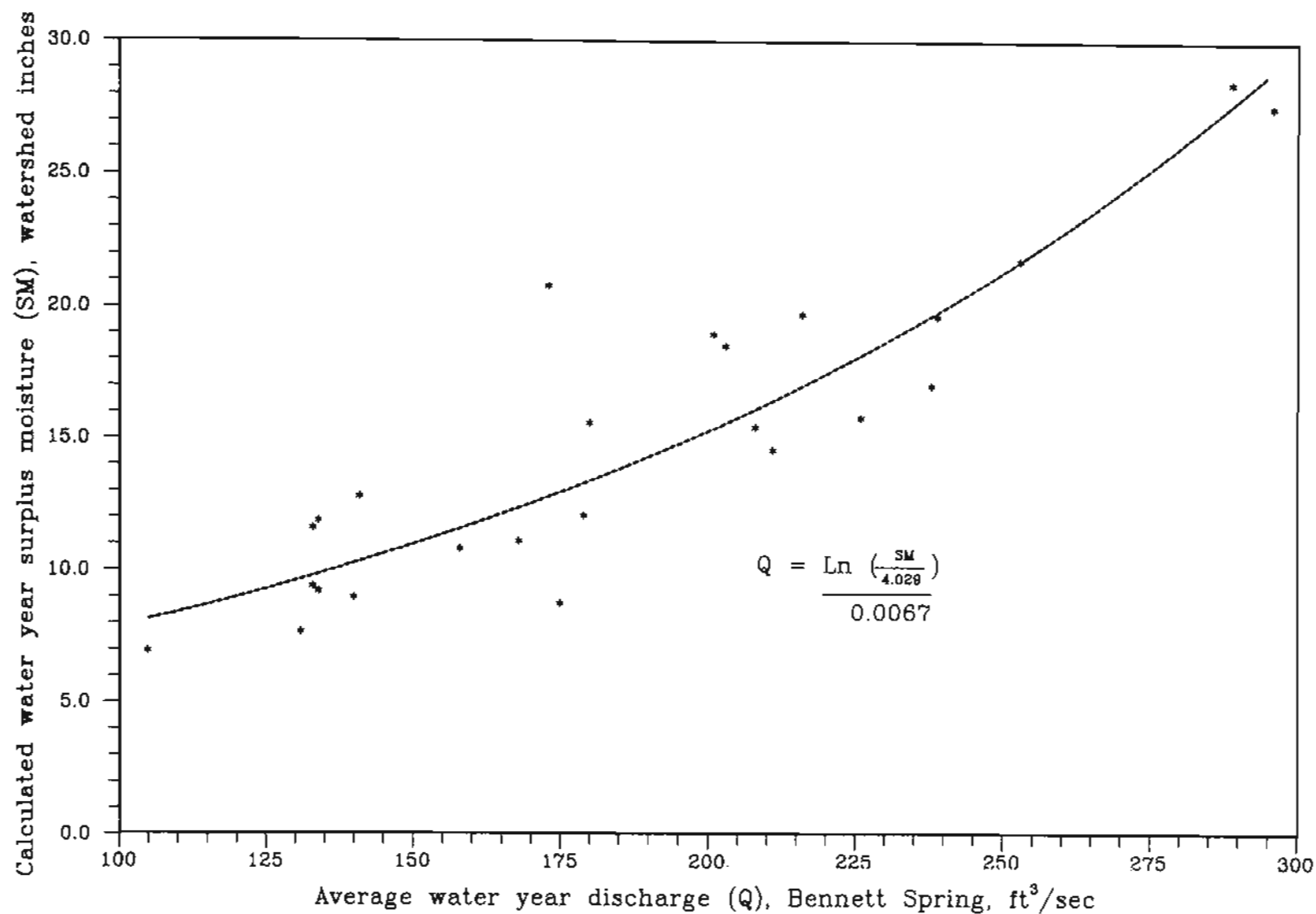


Figure 40: Surplus moisture versus discharge, water years 1966-1990, Bennett Spring.

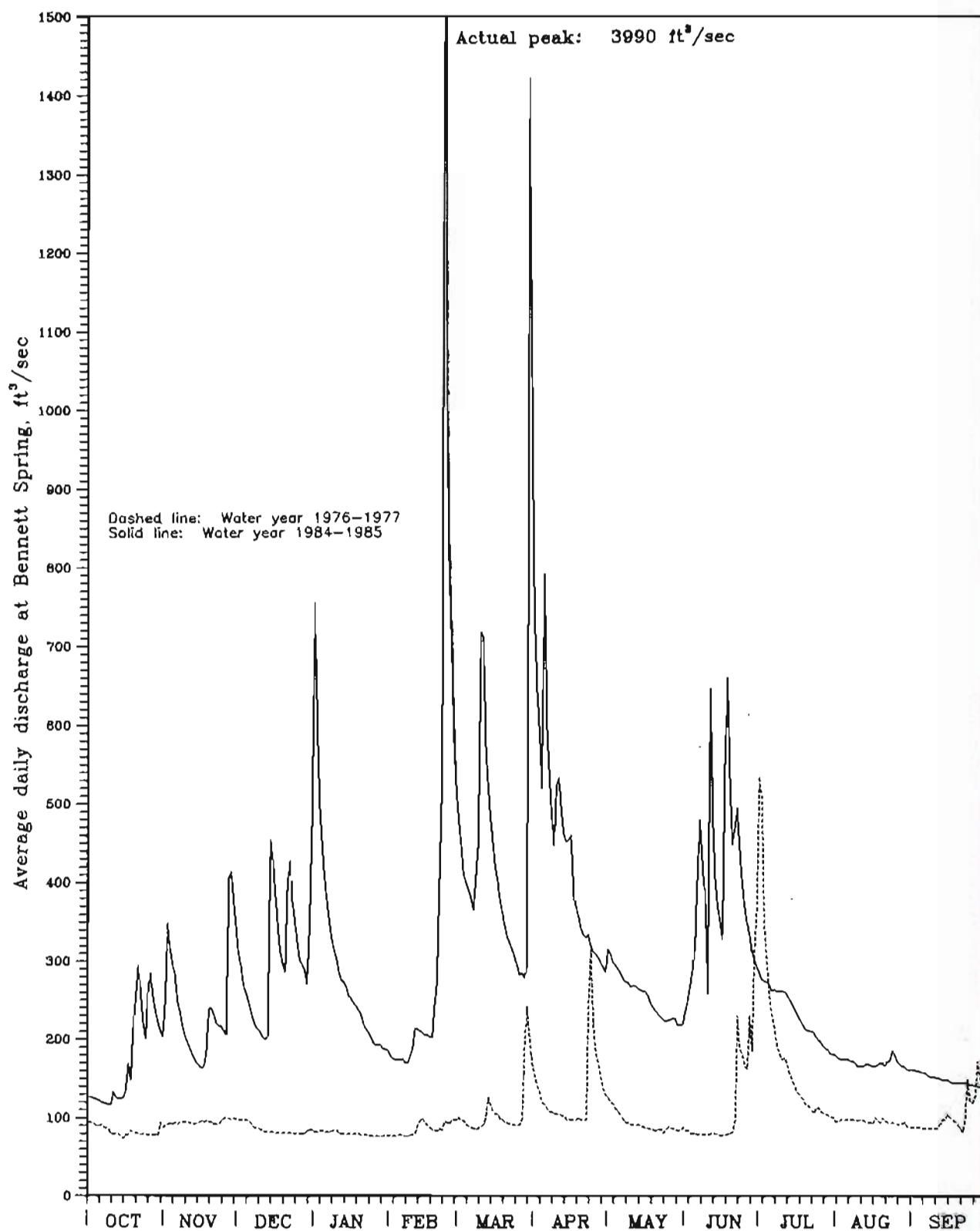


Figure 41: Hydrographs showing average daily flows at Bennett Spring during extremely wet and extremely dry years. Data source: U.S. Geological Survey.

erated by these rainfall events. The discrepancy is likely due to two factors: 1) The hydrologic budget assumes that no surplus moisture occurs unless precipitation exceeds evapotranspiration, and 2) soil moisture storage is at field capacity. For example, if 1.5 inches of rainfall occurred, and evapotranspiration was 0.25 inches, and soil moisture storage was 2 inches below field capacity, no surplus moisture would exist because the 1.25 inches of moisture remaining after evapotranspiration would not be enough to bring soil moisture storage up to field capacity. However, if soil moisture storage was only 0.5 inch below field capacity, then there would be 0.75 inches of surplus moisture. The soil moisture storage field capacity of 6 inches used in hydrologic budgets calculated for the Bennett Spring area represent an average value for the area, and significant variations likely occur.

Another factor that is not considered in the hydrologic budget is rainfall intensity. Three inches of precipitation occurring over a 24-hour period when soil moisture storage is low will generate little runoff into sinkholes and losing streams, and will likely be stored in soil materials. The same amount of rainfall occurring during a one-hour time period will likely generate significant runoff into losing streams, and generate discrete recharge even if soil moisture storage is below field capacity. In essence, when the rainfall rate is greater than the soil infiltration rate, runoff will occur. If the runoff is into a losing stream or sinkhole, groundwater recharge will occur, even if soils are not saturated.

Specific electrical conductivity data were collected at springs in the study area as part of this project. Specific conductivity is the electrical conductance of an aqueous solution as measured between opposite faces of a centimeter cube at 25°C. Pure water has a very low specific conductance, and conductivity increases as the amount of dissolved solids in the water increases. Different ion concentrations will cause differing increases in conductivity, so conductivity data will not accurately show specific ion content in natural waters, but conductivity data collected at a given spring will accurately show changes in dissolved solids content.

Specific conductivity data are useful for determining when discrete recharge from rainfall events

reach a spring. Rainfall typically has a low dissolved solids content, and thus has a very low specific conductivity. Dissolved solids in groundwater are primarily dissolved from the bedrock the water has been in contact with in the aquifer. Water entering the ground through a losing stream or sinkhole increases its dissolved solids load as it moves through the aquifer, but because it moves through the aquifer quickly, the water emerges at a spring before it reaches chemical equilibrium with the rock. At a spring, specific conductivity is generally highest in late summer and early fall when recharge is low and most of the discharge is water that has been in contact with the aquifer for a relatively long period of time. Conductivity is lowest during periods of high discrete recharge when large volumes of low-conductivity water is being channeled through the aquifer.

A specific conductivity transducer and datalogger was obtained for this project, and was installed at Bennett Spring to collect hourly specific conductivity data. However, the transducer was poorly suited for measuring relatively small changes in conductivity, and failed to operate properly. A new transducer, designed and built to measure relatively small changes in low-conductivity waters, was not received until the end of the project, so hourly specific conductivity data are not available. Specific conductivity was measured manually at Bennett Spring at approximately 1-week intervals during water year 1989-1990. Temperature data were also collected at approximately the same interval. These data, along with Bennett Spring average daily discharge (corrected for runoff from Spring Hollow), and weighted recharge area precipitation are shown in figure 43. Temperature of Bennett Spring varied about 3°F throughout the water year, and averaged about 56.5°F. Specific conductivity was highest during low-recharge periods in late summer, 1989, and early winter, 1990. Conductivity was lowest in spring and early summer, 1990, when discrete recharge was highest.

Figure 43 also shows that Bennett Spring responds very quickly to discrete recharge. Depending on soil moisture conditions, discharge at Bennett Spring begins increasing within a few hours after significant rainfall occurs. However, specific conductivity measurements and dye tracing data show that it takes from several days to several weeks for most recharge to reach Bennett

Spring. The rapid increase in flow at Bennett Spring after heavy rainfall is due to an increase in head pressure in the recharge area. Discrete recharge enters the groundwater system quickly, and increases the head pressure in the conduits, forcing the water already in the system to be expelled more quickly. The same process can be demonstrated using a faucet and long hose. The flow rate of a hose discharging water from a partly opened faucet will increase almost instantly if the faucet is opened to its maximum, but the water causing the increase in flow does not reach the end of the hose for some time. Thus, even though Bennett Spring discharge increases quickly after recharge, most of the water causing the increase in flow does not reach the spring for several days.

Figure 44 helps show the relationship between recharge, discharge, and specific conductivity at Bennett Spring. The data are from October, 1990. Flow data from Spring Hollow at King Farm and Spring Hollow upstream of Bennett Spring are from hourly values. Bennett Spring discharge data are 15-minute values. Precipitation, measured at the tipping bucket rain gage and event recorder in upper Spring Hollow watershed, is shown in four-hour increments. Conductivity was measured eight times during the month.

September, 1990, was relatively dry, and soil moisture storage on September 30 was about 3.05 inches, well below the assumed field capacity of 6 inches. Spring discharge was less than 150 ft³/sec, and conductivity was relatively high, about 380 umhos/cm. Rainfall began occurring about 1000 hours on October 3, and ended about 2200 hours with a total rainfall of 1.92 inches. Discharge began increasing at Bennett Spring about 1800 hours, peaked approximately six hours later, and declined over the next three days to nearly pre-rainfall discharge conditions. Specific conductivity remained essentially unchanged, and no surface-water runoff occurred in Spring Hollow at either of the gaging stations. On October 7, at about 0400 hours, another rainfall event began in upper Spring Hollow. This storm dropped 1.76 inches of rainfall in a four-hour period. Flow began increasing at Bennett Spring at about 0800 hours, peaked at approximately 2300 hours, and began decreasing. Light rain continued falling through October 7 and October 8, with intensity beginning to increase about 1200 hours on October 8. Rainfall intensity was highest between 1600 and 2000

hours. Total rainfall for the day was 1.60 inches. Discharge at Bennett Spring began increasing at about 1900 hours on October 8, peaked at about 1000 hours on October 9, and declined the remainder of the month. Light rain continued through October 9 with a daily total of 0.41 inches. From October 3 through October 9, there was a total of 5.70 inches of rainfall.

The cumulative effects of 3.36 inches of rainfall on October 8 and 9 generated enough surface-water runoff within Spring Hollow watershed to cause flow in Spring Hollow. At King Farm, flow began on October 8 at about 2000 hours. Flow peaked about four hours later at about 6.0 ft³/sec, declined sharply the next few hours, and ended October 12. Significant flow did not begin in Spring Hollow just upstream from Bennett Spring until about 0400 hours on October 9. Here, flow peaked about 1200 hours on October 9, and decreased over the next 36 hours to a small flow which continued much of the remainder of the month. Peak flow was about 7.5 ft³/sec.

Specific conductivity at Bennett Spring dropped slightly between about October 5 and October 10, probably due to the arrival of very local recharge that occurred on October 3. Conductivity dropped more sharply after October 10, reaching its low on about October 25. The time of lowest conductivity is considered to mark the arrival of the mass-center of the recharge. Since recharge occurred several times between October 3 and October 9, this indicates an average travel time of from 16 to 25 days, which is also supported by dye tracing data.

As a result of this study, the Bennett Spring recharge area, as well as recharge areas for other springs in the study area, has been established with a reasonable degree of certainty. The hydrologic characteristics of area losing streams are much better known, and the recharge and flow characteristics of Bennett Spring are better understood. Although groundwater recharge and groundwater discharge points have been identified, little is known about the actual route groundwater follows between the site of recharge and the receiving spring. Dye tracing is used to show the connection between the two points, and the bearing of a straight line connecting the dye injection and recovery sites shows the average direction the dye travelled. It is quite possible, even probable,

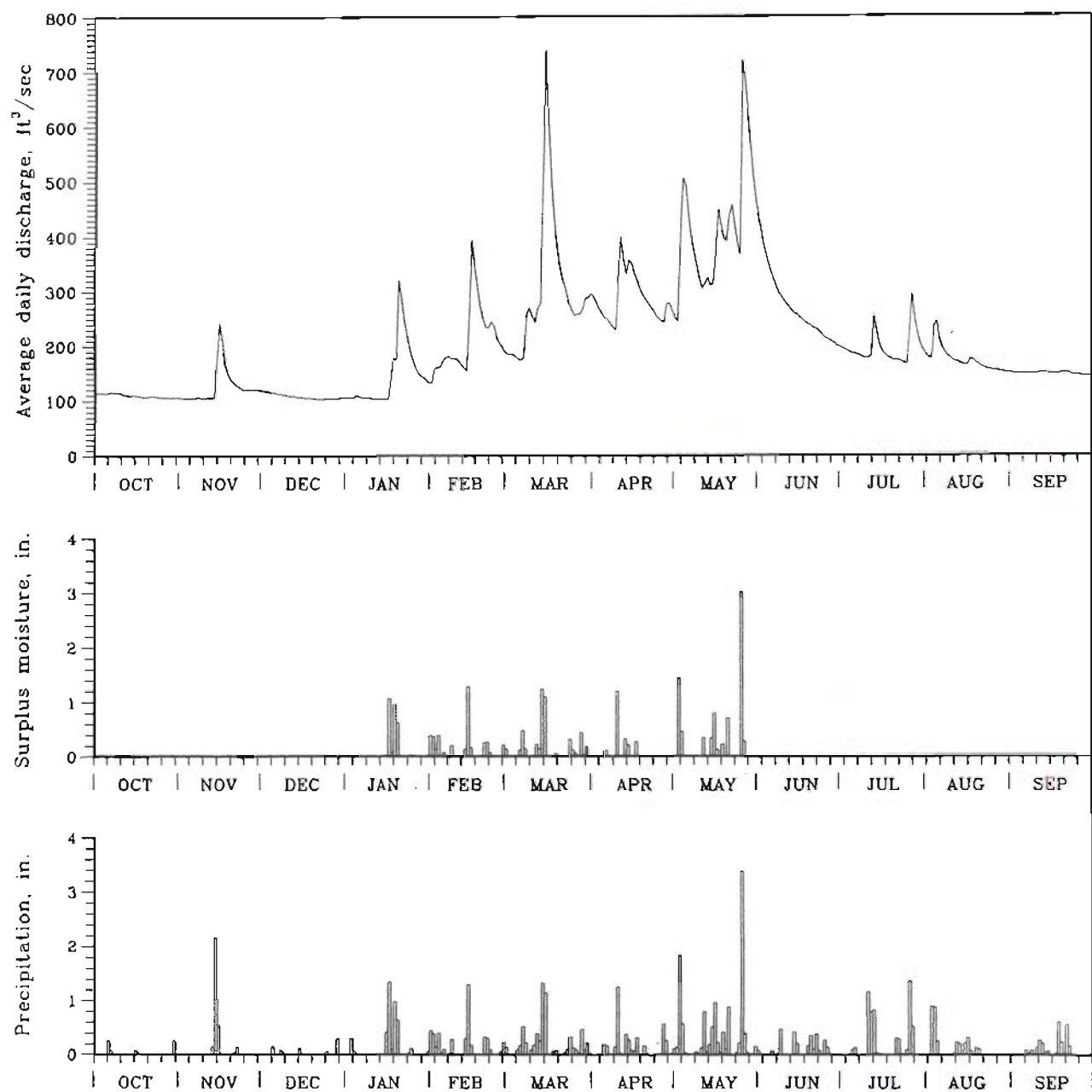


Figure 42: Weighted recharge area precipitation, calculated recharge area surplus moisture, and discharge at Bennett Spring, water year 1989-1990.

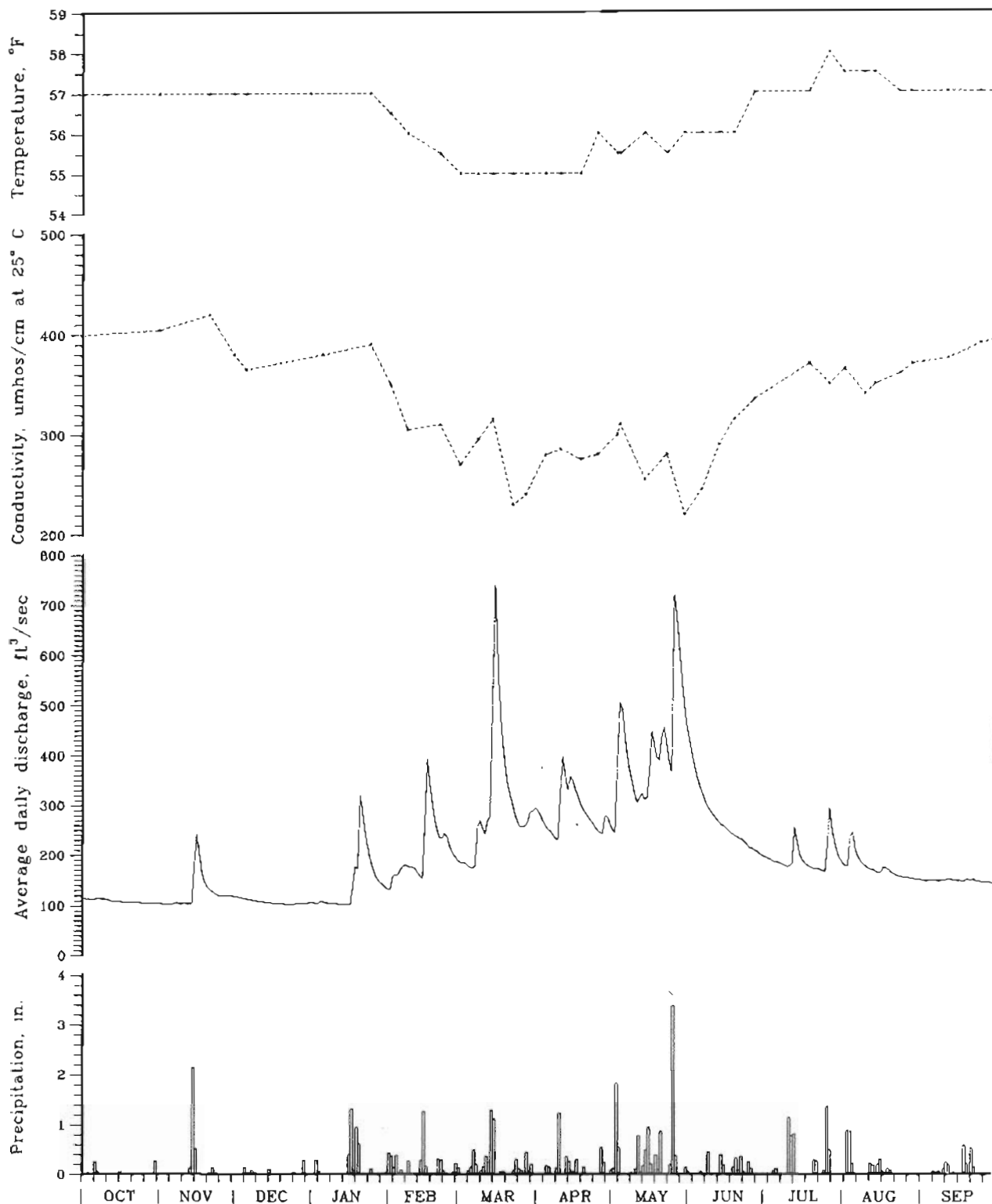


Figure 43: Weighted recharge area precipitation, and discharge, conductivity, and temperature at Bennett Spring, water year 1989-1990.

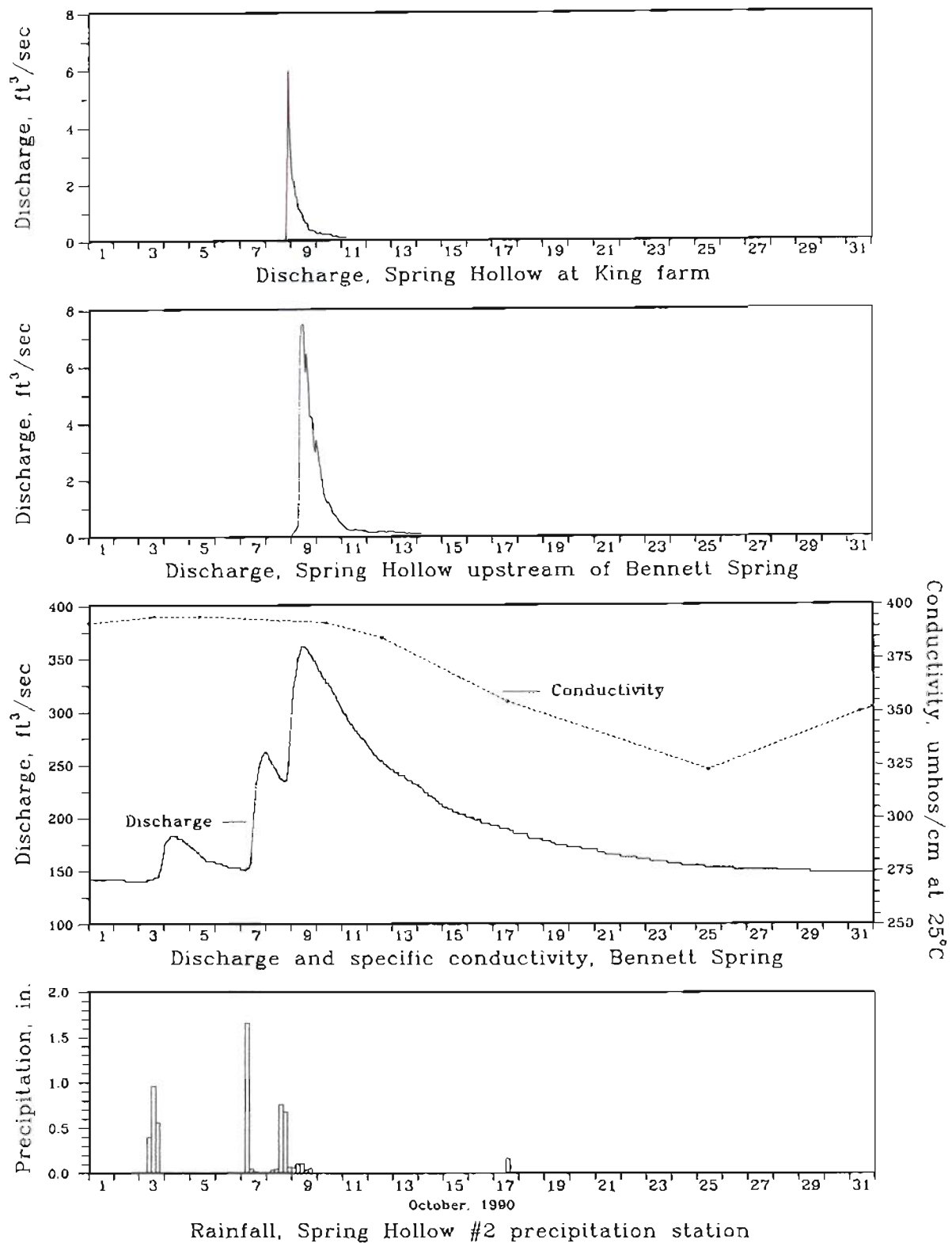


Figure 44: Hydrologic relationship between rainfall, Bennett Spring's discharge, and surface-water runoff in Spring Hollow during October, 1990.

that groundwater traveling in conduit systems follows a circuitous route. Extensive air-filled cave systems often have numerous passages that branch from a more central trunk passage. Water flowing through such a cave will travel much further than the straight-line distance. There is no reason to believe water-filled conduit systems channelling water to major springs are any less complicated. Air-filled caves that can be explored today were, in the past, groundwater conduits that were exposed and drained as erosion lowered the Earth's surface, and valleys cut through them. The cave passages do not usually coincide with valley development, so there is no reason to believe the conduits transporting water to springs coincide with surface drainages. Indeed, in the case of Bennett Spring, dye tracing shows recharge originates not only in the Niangua River basin, but also from within the Osage Fork of the Gasconade River basin and Goodwin Hollow, in Grandglaze Creek basin.

Though the exact path groundwater travels through the subsurface cannot ordinarily be determined by dye tracing, dye tracing information, combined with potentiometric-map data, can indicate the general route of travel. Figure 33, the potentiometric map of the Bennett Spring area, depicts water-level elevations measured in wells penetrating the Roubidoux Formation and Gasconade Dolomite, the same rock units that the Bennett Spring conduit system is likely developed in. The map shows a narrow zone of low groundwater elevations—a groundwater trough—extending from Bennett Spring, southeast, to the Osage Fork. Two dye traces, Brush Creek Tributary trace (DT 11) and Bear Thicket sink trace (DT 13), were conducted along this zone. Groundwater velocities calculated from the two traces averaged about 1.3 miles per day, considerably greater than ve-

locities of other dye traces in the area. A groundwater conduit serves as a drain. Ordinarily, head pressure inside it is lower than pressure around it, so groundwater in the adjacent aquifer moves toward the conduit. Water levels in wells drilled near a conduit would reflect this. Recharge directly entering a major conduit would follow a more direct path having less resistance than recharge taking place adjacent to the conduit. It is quite possible that a major conduit which transports water to Bennett Spring trends southeast from the spring, roughly paralleling Spring Hollow, and extends beneath the Niangua River basin surface-water divide into Osage Fork basin. Three other dye traces, Dousinbury Creek trace (DT 17), Spring Hollow trace (DT 18), and Spring Hollow Tributary trace (V & E, 1987), with injection sites on the flanks of this theorized conduit, had much slower straight-line groundwater velocities.

The potentiometric map shows other such groundwater troughs. Most notably, one extends across upper Dry Auglaize Creek and Goodwin Hollow trending to the northeast. It shows groundwater movement from Goodwin Hollow watershed into the Niangua River basin. Another apparent groundwater trough extends to the east across upper Parks Creek into Steins Creek watershed. Other hydrologic features probably exist that are not reflected on the potentiometric map. Detection of conduits in karst areas using potentiometric data depend greatly on data density. Since the data points are water wells, data are not available in areas where wells do not currently exist, and many areas may not have a high enough well density to accurately show the potentiometric surface.

REFERENCES CITED

- Dean**, Thomas J., Williams, James H., Lutzen, Edwin E., and Vineyard, Jerry D., Geologic report on the Bennett Spring project, Laclede and Dallas counties: Missouri Department of Natural Resources, Division of Geology and Land Survey, unpublished manuscript in Environmental Geology files, 18 p.
- Duley**, James E., Whitfield, John W., Vandike, James E., and Rueff, Ardel W., 1992, Geologic and Hydrologic resources of Laclede County, Missouri (OFR-92-90-GS); Missouri Department of Natural Resources, Division of Geology and Land Survey, 30 p., 15 maps (OFM-92-281-GS through OFM-92-295-GS).
- Gann**, E.E., Harvey, E.J., and Miller, D.E., 1976, Water resources of south-central Missouri: U.S. Geological Survey, Hydrologic Investigations Atlas HA-550, 4 sheets.
- Harvey**, E.J., Skelton, John, and Miller Don E., 1983, Hydrology of carbonate terrane-Niangua, Osage Fork, and Grandglaize basins, Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report No. 35, 136 p.
- Middendorf**, Mark A., Thomson, Kenneth C., Easson, Gregory L., and Sumner, H. Scott, 1987, Bedrock geologic map of the Springfield 1° X 2° quadrangle, Missouri: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1830-D, 1:250,000, 1 sheet.
- Missouri** Division of Environmental Quality, 1990, Monthly activities report for August, 1990: Missouri Department of Natural Resources, Division of Environmental Quality, Waste Management Program, unpublished report, 93 p.
- Offield**, T.W., and Pohn, H.A., 1979, Geology of the Decaturville impact structure, Missouri: U.S. Geological Survey, Profession Paper 1042, 43 p.
- Porter**, David, 1986, Characteristics of divable springs in Missouri-diver observations in Bennett and Roubidoux Springs: Unpublished report in Missouri Speleological Survey files, 11 p.
- Skinner**, Glenn "Boone," 1979, The Big Niangua River: Litho Printers, Cassville, Missouri, 153+ p.
- U.S. Army** Corps of Engineers, 1982, HEC-2 water surface profiles users manual: U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California, September 1982, 40 p. plus appendices.
- Vineyard**, Jerry D., and Feder, Gerald L., 1974, Springs of Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report No. 29, 267 p.
- Thornthwaite**, C.W., and Mather, J.R., 1955, The water balance: Drexel Institute of Technology, Laboratory of Climatology, Publications in Climatology Volume VIII Number 1, 104 p.
- ____ and ____ , 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Institute of Technology, Laboratory of Climatology, Publications in Climatology Volume X Number 3, 311 p.
- Willmont**, C., 1978, Algorithm for calculating the water balance: University of Delaware, Department of Geography, 15 p.

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Water Resources Report No. 38



**THE HYDROGEOLOGY OF THE BENNETT SPRING AREA,
LACLEDE, DALLAS, WEBSTER, AND WRIGHT COUNTIES, MISSOURI**

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